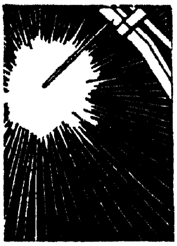
PROCEDURE HANDBOOK
OF ARC WELDING
DESIGN AND PRACTICE

George A Hougan

PROCEDURE HANDBOOK OF ARC WELDING DESIGN *and* PRACTICE



SIXTH EDITION

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Preface

Many important improvements in the electric arc welding process have occurred in the last few years. These improvements have extended the field of practical application of the process. They have increased the rate of weld production and enhanced the physical values of weld metal. Thus arc welding now obtains new and greater economies than ever before.

This Handbook has been designed to present in convenient form for ready reference the basic information on arc welding in its present status. Its contents include not only a complete description of the arc welding process in its various forms but also the essential data for its use in welding various types of steel, iron and non-ferrous metals. What one may expect from welds is answered in a section of the Handbook devoted to the structure and properties of weld metal.

Design is closely allied with the application of welding . . . for welding allows the designer greater latitude in selection of material and its utilization. A large portion of this Handbook is therefore devoted to designing for arc welded construction of machinery and structures. Many design examples of machinery elements and units are included, also examples of various forms of structural details applicable to many types of structures.

Another section of this Handbook has been devoted to typical applications of arc welding in manufacturing, construction and maintenance which illustrates to a small extent the wide and varied use of the process and its potentialities as an industrial tool. The illustrations and brief descriptions of these typical applications may offer suggestions which may be profitably incorporated in the design or construction of one's own products.

THE LINCOLN ELECTRIC COMPANY

Cleveland, Ohio
August, 1933

Preface to Enlarged Edition

The publication of this new edition has been made necessary by an acceptance of the Handbook which exhausted the large supply of the original edition in less than five months after issue. To be consistent with the Lincoln policy of constant product improvement many additional pages of data are included in this enlarged edition which increases the Handbook's utility as a source for practical information on arc welding and its application. The additions to the original text include such subjects as Weld Inspection, Study of Stress Distribution, Approximate Method of Designing and others, also additional data on procedures for welding mild steel, copper and aluminum.

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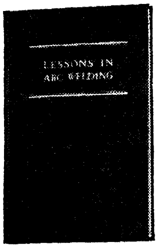
Cleveland, Ohio
February, 1940

Aids for Arc Welding Progress

In the interests of scientific and social advancement through the use of arc welding, the Publishers of this book also have other books and bulletins on the various phases of arc welding application for sale. The following books are recommended for engineers, designers, production supervisors, shop men, welders, students and others seeking advancement through knowledge of arc welding.



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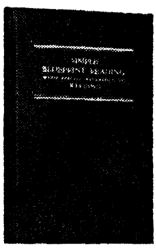

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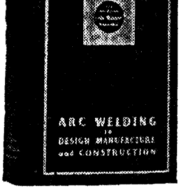

"Arc Welding in Design, Manufacture and Construction"

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Make checks or money orders out to THE JAMES F. LINCOLN ARC WELDING FOUNDATION.

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PROCEDURE HANDBOOK OF ARC WELDING DESIGN AND PRACTICE

PART I

WELDING METHODS AND EQUIPMENT

This book deals with the electric arc welding process and its applications. However it is desirable that the reader have some knowledge of the other welding processes, their fields of application, limitations, the equipment involved and welding method employed.

Exclusive of arc welding there are the following welding methods or processes:

1. Forge or fire welding
2. Thermit welding
3. Resistance welding
4. Oxy-acetylene or gas welding
5. Atomic hydrogen arc welding.

FORGE WELDING

Forge welding is the method of the blacksmith shop. The metal is heated in the forge to a plastic stage and hammered on the anvil. Because of its cost and obvious slowness this method is not a process which can be used widely in production manufacturing. For certain classes of work this process has been improved by the development of heating furnaces and power hammers. The range of applications, however, is extremely narrow. Until recently large quantities of steel pipe were manufactured by this method; however, electric welding has replaced forge welding to a large extent even in this particular field. Practically all high pressure vessels were formerly made by forge welding, but here again arc welding is making rapid progress. In structural steel construction as used in building it is obviously out of the question to use forge welding.

THERMIT WELDING

Thermit welding is essentially a casting process. It employs chemical reaction obtained by igniting a mixture of finely divided aluminum and iron oxide. During the reaction the oxygen leaves the iron oxide to combine with the aluminum. The free iron is drawn off when at very high temperature into a mold previously prepared around the parts to be welded. These parts are brought to red heat before the liquid metal is poured into the mold. When this is done the parts in the mold dissolve in liquid metal which when cooled become a single homogeneous section. The process requires the use of specially made containers and specially prepared mixtures, together with molding materials, preheating equipment and various accessories. Thermit welding has a certain usefulness in

the repair of heavy parts but because of the necessity for molds and dams its wide application is limited.

RESISTANCE WELDING

Resistance welding is a heat and squeeze process. The parts to be welded are raised to the temperature of fusion by the passage of a heavy electrical current through the junction. When the welding heat has been reached, pressure is applied mechanically to bring about the union. The field of resistance welding is in turn broken down into several processes, the most important of which are spot welding, butt welding, flash welding and seam welding.

The spot weld is made by overlapping the parts and gripping the overlapped sections between two electrode points, through which the current is passed and pressure applied to make the weld in a single spot. The butt weld places the parts to be welded end to end, to be heated electrically and squeezed together. The flash weld is an adaptation of the butt weld. The seam weld is similar to the spot weld except that a circular rolling electrode is used to produce the effect of a continuous seam. A special spot-welding operation known as "shot welding," employing carefully controlled short time intervals and high currents, is often used for special alloy steels such as the "stainless group." Resistance welding has a limited application in general manufacturing because special equipment is usually required for each individual welding job. It is therefore practical chiefly for mass production.

GAS WELDING AND CUTTING

In gas or oxy-acetylene welding a high temperature flame is produced by igniting a mixture of two gases, usually oxygen and acetylene, in correct proportion and at proper pressures. The welding is brought about by first preheating with the torch flame the metal pieces to be welded, at point of contact; after this, when the base metal is at molten temperature, the weld metal is added by melting with the torch flame a filler rod of suitable composition. Gas welding is a puddling process; i.e., the molten metal forming the weld is in a small pool over which the flame is constantly played. Making a weld by this process consists largely in causing this pool to move by melting metal away ahead of the pool and letting the metal cool behind it.

The gas welding process requires a suitable supply of both oxygen and acetylene, suitable devices for adjusting the mixture and regulating its flow, and various accessories. Gas welding has been used more extensively than forge, thermit or resistance welding, due to the flexibility of the equipment and small investment it requires. Notwithstanding the comparatively low first cost of equipment, the high operating cost usually makes it less economical than arc welding for production work.

The same gases used for welding are also used for cutting metal. For this work a cutting torch is employed, and this process becomes an important adjunct to arc welding, it being an economical and practical tool for cutting unusual metal shapes prior to assembly by welding with the electric arc. This is generally known as flame cutting or flame machining.

ATOMIC HYDROGEN ARC WELDING

In the atomic hydrogen welding process, an alternating-current arc is maintained between two tungsten electrodes, and, at the same time, a stream of hydrogen gas is passed through the arc and around the electrodes. The heat of the arc breaks up the molecules of hydrogen into atoms which recombine outside of the arc to form molecular hydrogen. The very intense heat given off by the atomic hydrogen as it reverts to the molecular form is used to fuse the metals to be welded. The tungsten electrodes do not enter into the weld; they are used only as a means for establishing and maintaining the arc. They are, however, slowly evaporated by the intense heat.

The metal or work being welded does not, as in the metallic-arc process of welding, form a part of the electric circuit. Therefore, it does not need to be grounded. The actual manipulation of the electrode holder is similar to the manipulation of the gas torch used in oxy-acetylene welding. The flame is played over the edges to be joined, causing them to fuse together. On thick stock, a filler rod may be fused into the weld.

Atomic hydrogen arc welding, somewhat more costly than usual arc welding methods, is used for general welding of steel and ferrous alloys; for welding thin sheet metals; and for welding various non-ferrous metals and alloys.

ARC WELDING

In arc welding the pieces of metal to be welded are brought to the proper welding temperature at point of contact by the heat liberated at the arc terminals and in the arc stream so that the metals are completely fused into each other, forming a single solid homogeneous mass, after it solidifies.

An electric arc is nothing more than a sustained spark between two terminals or electrodes. In arc welding the arc is formed between the work to be welded and an electrode held in a suitable holder. The instant the arc is formed, the temperature of the work at point of welding and the welding electrode jumps from normal to the vicinity of 6500 degrees Fahrenheit.

This tremendous heat is concentrated at the point of welding and the end of the electrode. It melts a small pool of metal in the work and heats the end of the electrode. Additional metal required is obtained from the electrode, in case of metallic electrode, or by a filler rod which is fed into the arc—melted and deposited. Filler rod may be used with either metallic or carbon electrode.

Metallic Arc Welding.—In the metallic arc process, the arc occurs between the work to be welded and a metallic wire. Under the intense heat developed by the arc a small part of the work to be welded is brought to the melting point almost instantaneously. The other end of the arc, the tip of the metallic wire, is likewise melted and tiny globules of molten metal form. Those globules are then forced across the arc and deposited in the molten seat waiting for it in the work. The globules are actually forced across the arc and not dropped as gravity does nothing more than assist this deposition of metal when the work is flat.

It is this fact which permits the use of metallic arc welding in overhead welding.

Carbon Arc Welding.—In carbon arc welding the arc is formed between the work and a carbon rod held in the electrode holder. The heat of the arc melts a small pool in the surface of the work to be welded. This pool is kept molten by playing the arc across it and extra metal to form the weld is added by a filler rod. Carbon arc welding is a puddling process, and is not applicable to vertical or overhead welding. Its greatest application is in automatic welding or in specialized applications.

The carbon arc may also be used as an economical cutting tool in many cases, particularly where it is desired to dismantle an assembly, cutting risers or where a very smooth cut is unnecessary.

THE SHIELDED ARC

It is common knowledge that molten steel has an affinity for oxygen and nitrogen. When exposed to the air, molten steel enters into chemical combination with the oxygen and nitrogen of the air to form oxides and nitrides in the steel. These impurities in the steel tend to weaken and embrittle it as well as lessen its resistance to corrosion.

In the ordinary arc the molten globules which pass from the electrode to the work are exposed to the ambient atmosphere which contains chiefly oxygen and nitrogen. The molten base metal is also exposed to these elements. They combine with the molten metal forming oxides and nitrides in the weld metal. If the metal during the fusion process is completely protected from contact with the ambient atmosphere the injurious chemical combination cannot take place. This can be achieved by completely shielding the arc.

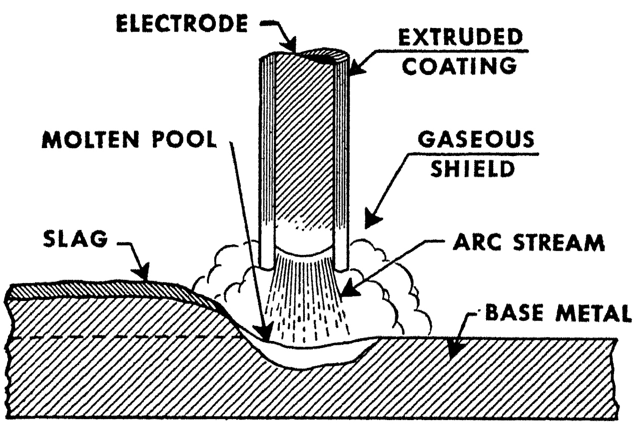

Fig. 1. Diagrammatic sketch showing shielding of arc and slag protection of weld metal while cooling.

An arc may be shielded by completely enveloping it with an inert gas, which will not enter into chemical combination with the molten metal and at the same time prevent its contact with the atmospheric oxygen and

nitrogen. Welds made with a completely shielded arc are largely free of oxides and nitrides and are therefore composed of metal having superior physical characteristics to that deposited by an ordinary arc. For example, welds made with a shielded arc have a tensile strength of 60,000 to 75,000 pounds per square inch which is 20% to 50% higher tensile strength than that possessed by welds deposited by an ordinary arc. The ductility of welds made with a shielded arc averages 100% to 200% greater. The resistance to corrosion of shielded arc welds is greater than even mild rolled steel and far greater than that of welds made with an unshielded arc.

In *manual welding* a shielded arc is obtained through use of specific types of electrodes which are heavily coated. The heavy coating is of such composition that in the heat of the arc it gives off large quantities of a gas which envelops and completely shields the arc from the ambient atmosphere, Fig. 1.

The electrode coating is consumed in the arc at a slower rate than the rate of deposition of the electrode metal. As a result, the coating extends beyond the metal core of the electrode and serves to direct and concentrate the arc stream.

The action of the arc on the coating of the electrode results in a slag formation which floats on top of the molten weld metal and protects it from the ambient atmosphere while cooling. After the weld metal is sufficiently cooled the slag may be easily removed.

In *automatic welding,* a completely shielded arc can be obtained in the carbon arc process. Since in this process there are no metallic electrodes and consequently no metal passing across the arc, the oxygen and nitrogen in the ambient atmosphere have less opportunity to combine with the molten weld metal. This protection is accomplished by the introduction of a specially prepared substance into the arc flame at the point of fusion. The combustion of this substance in the arc provides an inert gas which completely encloses and shields the arc from the ambient atmosphere. Another form of shield is obtained by automatic deposition of powder on the joint ahead of the arc. The arc penetrates through the powder to weld the joint. In addition to the inert gas formed, a slag is formed which floats on top of the molten metal and protects it from the atmosphere while cooling. These simple yet effective methods of shielding the arc permit very economical production of welds which possess physical properties in many respects equal to or better than those of mild rolled steel.

A shielded arc is also available for automatic metallic arc welding when an automatic electrode feeder is employed. In this method, use of specific types of heavily coated electrodes makes possible a shielded arc in the manner described previously under the subject of "manual welding."

Source of Current Supply for Arc Welding.—Arc welding requires a continuous supply of electrical current, sufficient in amount and of proper voltage. The voltage across the arc will in general range from about 15 volts to 45 volts, and in operation is constantly varying due to changes in arc conditions. The current ranges vary from 20-25 amperes to in some cases as high as 600-800 amperes. Either direct current or

alternating current may be used for welding. However, the former is by far the more commonly used.

Where direct current is used there are two methods used to obtain current of proper amount and voltage. The first method employed is a source of constant voltage in which is introduced a resistance in series with the arc to reduce the voltage to the proper value for welding. By this method the source of current is usually through large motor generator sets with the motor arranged for any commercial power supply. The generator is arranged to give a voltage of 70-100 volts direct current. This method, however, is usually wasteful, as a large amount of power is lost in the resistance used to reduce the voltage to that required for welding.

A later method, and the one most commonly used today, is a motor generator of the "variable voltage" type, as contrasted with the constant voltage type, the motor of this type of machine being arranged for any commercial power supply. The generator is arranged with such characteristics that the voltage automatically adjusts itself to the varying voltages demanded by the arc. This type of welding equipment eliminates the necessity for wasteful control resistance in the arc circuit. The variable voltage type welder is comparatively small in size, having easy portability. This allows the machine to be easily and quickly placed adjacent to the work to be welded and thus eliminates the extensive installation of large size wiring required by the other type of equipment to bring the welding current to the work wherever it may be placed in the shop. The variable voltage machine is the most widely used and the most economical type of welder.

Characteristics of the Welding Generator.—A welding generator has but one function and that is to make a good welded joint at low cost. This apparently simple purpose involves several very important characteristics of a welding generator. These may be divided into two groups—static and transient.

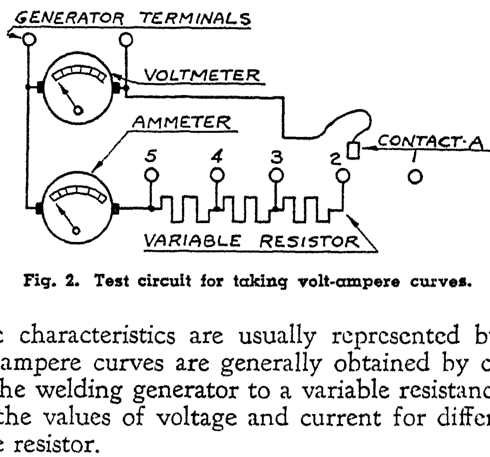

Fig. 2. Test circuit for taking volt-ampere curves.

The static characteristics are usually represented by volt-ampere curves. Volt-ampere curves are generally obtained by connecting the terminals of the welding generator to a variable resistance and reading and plotting the values of voltage and current for different resistance settings of the resistor.

For example, the circuit for taking volt-ampere curves may be as

shown in Fig. 2. The resistance of the resistor may be varied by connecting the moving contact, A, to any of the terminals, "1", "2", "3", "4" or "5".

Assuming the controls of the generator have been set, the volt-ampere curve for that setting is taken as follows: With the moving contact connected to terminal "1", the ammeter indicates zero because there is no contact between "1" and the rest of the resistor. The voltmeter indicates 98 volts. This is plotted as shown in Fig. 3, zero amperes and 98 volts. The moving contact is then connected to contact "2". The

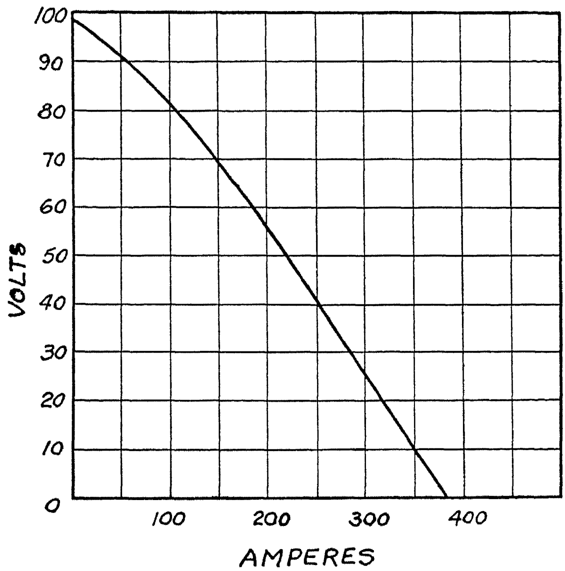

Fig. 3. A typical volt-ampere curve.

ammeter indicates 150 amperes and the voltmeter indicates 70 volts. This is plotted. In like manner, by connecting the moving contact, A, to contacts "3", "4" and "5" of the resistor, and by reading their respective volts and amperes, other points can be plotted. If a smooth line is drawn through the points plotted, one completed volt-ampere curve is obtained.

The curve shown in Fig. 3 is an actual curve which was taken on a standard welding generator. The circuit used in taking the volt-ampere curve was connected as shown in Fig. 2. Besides this one curve, in the modern generator with adequate control, literally hundreds, or thousands, of curves can be obtained. If the voltage control has 30 voltage steps, and if the current control has 100 steps, the total number of volt-ampere curves that are available would be 30x100, or 3,000 curves.

If the voltage control is set at the maximum, say 98, and the current control is varied from minimum to maximum, one hundred fan-like curves will be obtained from the 98-volt point. A few of these curves are shown in Fig. 4. If the voltage control is then set to obtain any other open circuit voltage and the current control is varied from minimum to

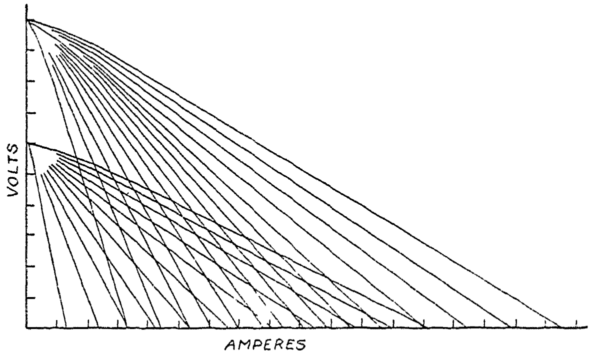

Fig. 4. A group of curves secured at various current and voltage settings.

maximum, one hundred fan-like curves will be obtained for this particular point. There will be one hundred curves obtainable for every voltage setting on the machine. Hence, in all there will be 30x100, or 3,000 possible volt-ampere curves on the basis above outlined.

It should be noted at this point that the shape of the volt-ampere curve through the operating range is of the utmost importance and that separate controls are desirable for voltage and current.

The welding performance, which is the ability of the arc to weld a good joint economically, depends on the arc watts, the arc length or voltage, and the arc current.

If the arc voltage is held constant and the arc current is varied, the arc watts will increase directly with the arc current, as arc watts equal the product of arc amperes and arc volts. Therefore, in Fig. 5, "arc watts" is shown as a straight line. When the arc current is low the welding performance is low because there is insufficient current to melt the

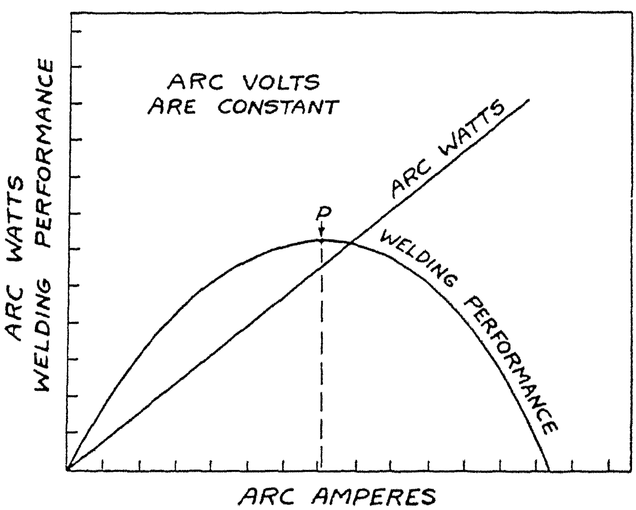

Fig. 5. Variation of arc watts and welding performance with arc current, arc volts constant.

electrode and the edges of the joint readily. As the arc current increases, the electrode melts more readily and the joint also is melted deeper, resulting in better penetration and fusion. The welding performance increases with the arc current until point P, of maximum welding performance, is reached. If the arc current is increased still more, the electrode melts faster than it can be deposited, too much metal adjacent to the joint is melted, metal is thrown out of the joint and possibly a hole is burned through the joint. The more the arc current is increased beyond point P, the poorer the welded joint becomes even though the arc watts are increasing. (See Page 127.)

If the arc current is held constant at its best value shown by point P, on Fig. 5, and the arc voltage is varied, a curve the shape of the one shown on Fig. 6 will be obtained. The arc watts will vary directly with the arc voltage or arc length and is represented by the straight line in Fig. 6. The arc watts curve does not start at zero voltage as an arc cannot be maintained unless the arc voltage is approximately 14 volts. As the voltage is increased the welding performance increases. When the arc voltage is low, the arc watts are concentrated in a very small area and insufficient metal is melted at the joint to give a good weld. Also the molten globules of metal passing from the electrode to the plate are continually causing approximate short circuits from the electrode to the plate. The continual short circuiting causes spattering and a high bead.

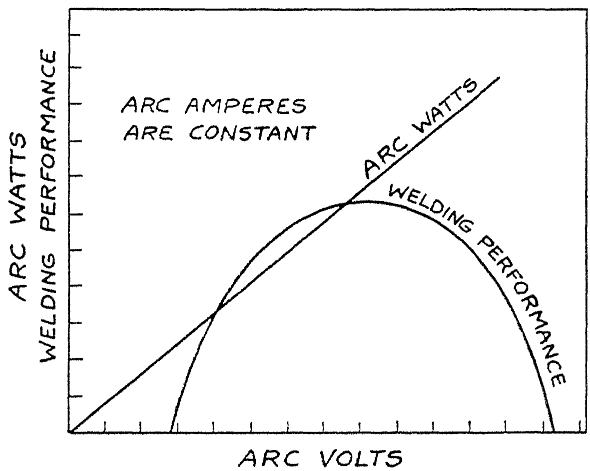

Fig. 6. Variation of watts and performance with arc volts, amperes constant.

As the arc voltage is increased, the objections mentioned above decrease until the proper arc voltage represented by point of maximum welding performance is reached (Fig. 6). When this point is reached the arc no longer causes a sputtering sound, due to continual short circuiting, and the arc has a steady sharp crackling sound, and good penetration is obtained.

If the arc voltage is further increased by lengthening the arc, a large portion of the arc watts will be radiated into the air where it is wasted,

and bubbles of metal will form on the end of the electrode. These bubbles frequently are thrown off to the side of the weld in the form of splatter. The arc will be wild and make a wide, shallow bead. It must be remembered that not only is the joint poor but the metal thrown out of the weld is lost and can never be reclaimed. As the arc voltage is further increased the condition mentioned above becomes worse. (See Page 127.)

The proper arc current and arc voltage vary with different types of joints, thickness of plate, the electrode used, etc. (See Procedure, Page 141.)

It is possible to design welding generators having the following characteristics:

1. The arc current remains constant even though the arc volts vary. This characteristic is represented by line A on Fig. 7.

2. The arc voltage remains constant even though the arc current varies. This characteristic is represented by line B, on Fig. 7.

3. The arc amperes increase as the arc volts decrease. Many different types of lines or curves could be drawn to represent this condition. Two of them are shown on Fig. 7 as lines C and D.

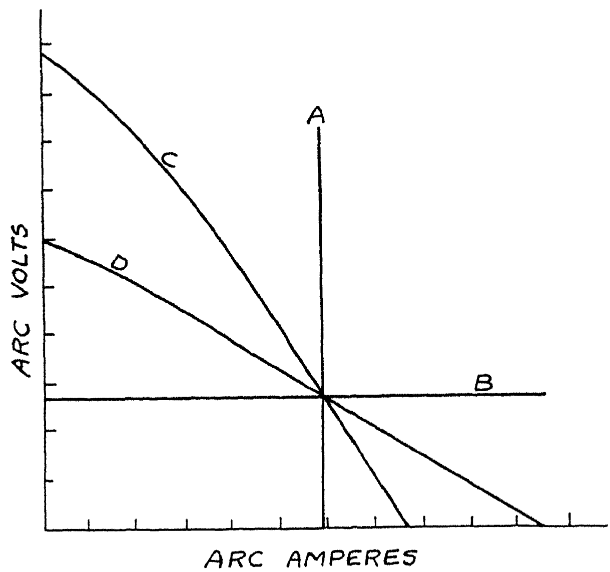

Fig. 7. Various types of volt-ampere curves.

If arc watts are plotted against arc volts for the volt-ampere curves shown in Fig. 7, the curves shown in Fig. 8 will be obtained.

Curve A on Fig. 8 is obtained from curve A on Fig. 7; curve B on Fig. 8 from curve B on Fig. 7, etc.

If a generator with a characteristic shown by curve A in Fig. 8 were used, it would be very difficult, under usual welding conditions, to make the arc go out when the weld is finished because the voltage will increase so rapidly when the arc is lengthened. The current remains

constant and cannot decrease, so that the arc can not go out. Therefore, it would be very difficult to use a machine of this type for welding within usual ranges or requirements.

If a generator with a characteristic shown by curve B in Fig. 8 were used, it would be impossible to weld. If the electrode were touched to the piece to be welded, the voltage would try to go to zero because the

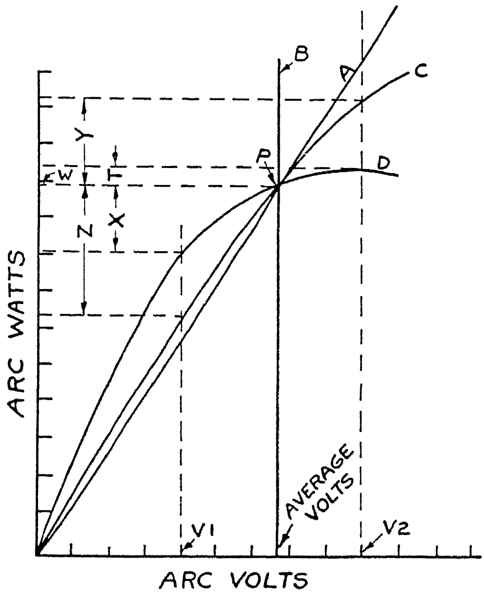

Fig. 8. Variations of arc watts with arc volts for volt-ampere curves shown in Fig. 7.

machine would be short circuited. Since the design of the machine will not let the voltage go to zero, an extremely high current will flow. Inasmuch as characteristics A and B cannot be used, the discussion will be confined to characteristics C and D.

Assume that during normal welding the arc voltage varies from value VI, to value V2, Fig. 8. Several factors cause this variation, such as melting off of the welding electrode which lengthens the arc, variation in fit-up of the joint, metal passing from the electrode to the weld, and variation in the arc length due to the fact that it is practically impossible and not always desirable to keep the distance between the tip of the electrode and the weld constant. The arc voltage midway between these two points will represent the average arc voltage. At the average arc voltage the arc watts will be represented by point W, on Fig. 8. If a generator with characteristic curve C is used, and if the arc voltage increases above the average voltage to V2, the arc watts will increase by Y watts as shown in Fig. 8.

In general, the increase in watts will not materially affect the weld. The bead will tend to become wider and shallower due to the increase in arc volts. This is partially overcome by the increase of the arc watts. If the arc voltage decreases to V1, the bead tends to become narrow and

the penetration would be increased if the arc watts did not fall off rapidly as shown by Z in Fig. 8. Since the arc watts fall off so rapidly, penetration will decrease slightly.

This is highly desirable for a number of conditions such as when welding thin gauge metal or some metals such as aluminum, because if the penetration increased it is likely a hole would be burned through the weld. When welding on this gauge metal a tendency to burn through will be overcome by shortening the arc length.

If a generator with characteristic curve D, is used, and if the arc voltage increases to V2, the arc watts will increase by T watts as shown in Fig. 8. This does not materially affect the weld as the increase in arc length is partially overcome by the increase in arc watts. If the arc volts decrease to V1 due to a decrease in arc lengths, the arc watts do not fall off as much as when curve C was used. Therefore, penetration does not decrease but increases slightly because of the shorter arc length with a very small decrease in arc watts.

This type of curve (D) is highly desirable for such work as welding heavy plate because penetration is not decreased by shortening the arc length. This is also desirable on vertical and overhead where it is sometimes necessary to shorten the arc to prevent metal from falling out of the weld. If the arc watts decrease materially when the arc is shortened, penetration will be decreased and the rod is likely to stick to the weld because of the solidifying of a drop of metal passing from the electrode to the work due to insufficient arc watts.

From this discussion of curves and consequent performance it is evident that in those cases where all conditions are not fully known, it is advisable to start from the setting of minimum penetration or steep curve and adjust until the desired penetration is obtained.

Since the purpose of a welding generator is to deposit weld metal, and make joints in thin metal and thick metal, as well as metal of all kinds, it is necessary that it be equipped with proper controls to obtain required characteristics and adequate performance. Independent control of arc volts and arc amperes is of vital importance since it is necessary to have a great number of curves to meet all conditions of which the above two are examples.

As mentioned above, the welding generator must deposit high quality metal at low cost. To do this the generator must properly control the shape of the volt ampere curve. It must also have the proper transient characteristics to produce a sound weld without wasteful spatter.

Conditions during operation of an arc are not constant or fixed but are constantly changing, i.e., under transient conditions. Due to the transfer of molten metal across the arc and gaseous conditions, the volt-ampere demands of the arc are constantly changing. If the arc demands a high voltage, the generator must respond, or if a low voltage it must also respond. The voltage must not go too low or the arc will go out. It is easy to maintain a 1/8″ arc at a relatively low voltage due to the conducting gases in the arc, but as these gases become non-conducting very quickly (in a few thousandths of a second), if the voltage does not rise, the arc goes out. If the current rises to a very high value, results

are spatter and explosive action on the bead. If current does not reach a value sufficient to melt the electrode and metal, there is no fusion.

In both voltage and current, the generator must respond to the arc condition very quickly, in fact, practically instantaneously. There must be no instability. The response must meet the arc demands as they occur, to the degree required—no more and no less.

This response to arc demands or conditions to the required degree results in the deposition of good sound weld metal.

A generator which will produce the type of curves shown (C and D, Figs. 7 and 8), which will respond to arc conditions instantaneously, which will supply energy for adequate fusion—that generator will minimize spatter loss, assure good welding speed and produce good sound welded joints economically.

The practical man or layman may ask what this rather technical discussion means. Why should he be interested? How is his work affected?

A welding generator is usually required to do a variety of work. Today it is used on light gauge material, tomorrow on heavy stock—today welding downhand or flat, tomorrow vertical or overhead—today mild steel, tomorrow some alloy or non-ferrous metal. So, the welding generator which will best meet this varied requirement is most desirable.

A welding generator which permits a great variety of volt ampere characteristics thus will allow the welder to select the type of curve or characteristic best adapted for the kind of work he is doing. A few examples will illustrate this point.

For thin material, as 18 gauge steel, a high setting of the voltage control and a low setting of the current control is desirable, producing a curve such as (1), Fig. 9.

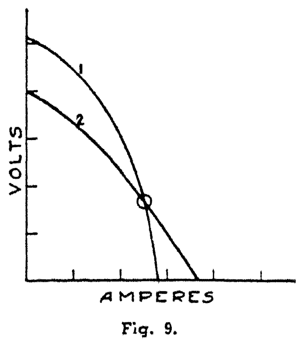

Fig. 9.

Since the current increases or changes only a small amount there is less tendency to "burn through" with this characteristic.

Now, suppose you are welding a casting and you want the same current and actual arc voltage, but you have other problems to meet, of which burn-through is not one. Then a curve such as (2) is desirable. The open circuit or idle voltage setting is a little bit lower and the current

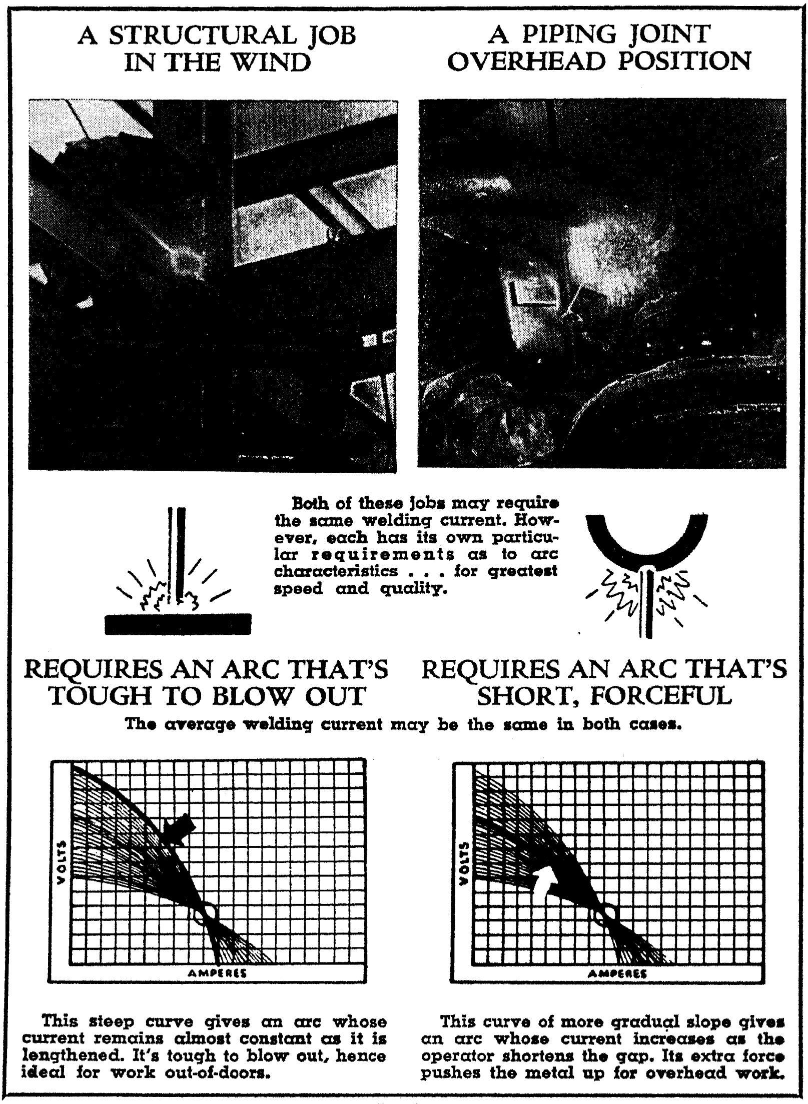

Fig. 10.

control setting is a little higher. However, note that the welding volts and amperes are the same in both cases.

Out-of-doors construction work, where windy conditions are severe, requires an arc which "won't blow out." A steep curve, giving an arc whose current remains nearly constant as the arc is lengthened, is desirable. (See Curve 3, Fig. 11.) The same current and arc voltage may be required for an overhead pipe job in which case a curve such as (4) is desirable where the current increases as the welder shortens the arc, providing extra force to help "push the metal up" for the overhead work. This point is illustrated in Fig. 10.

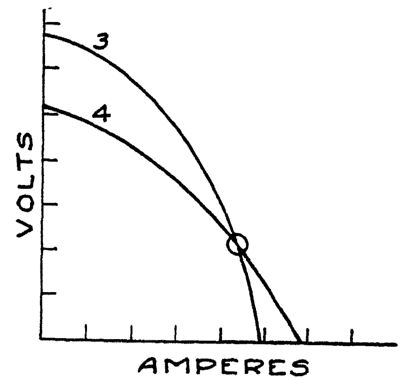

Fig. 11.

Similarly, for tank or pipe welding with large electrodes, a curve such as (5) of Fig. 12 may be used. And for work such as butt welding

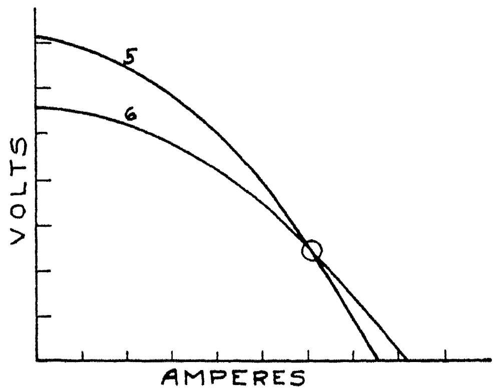

Fig. 12.

3/8″ plate with square-groove joint, curve (6) may be used. Note carefully that while only three different arc voltage and arc ampere values are shown—six different settings are shown—a voltage setting for each and a current setting for each.

These few illustrations have been given to show the practical desirability of being able to not only vary the amount of current but to vary the characteristics of that current by varying the slope and position of the volt ampere curve. The relation of the various curves referred to is shown in Fig. 13.

As stated on Page 9, many combinations of open-circuit voltage and welding current are available, resulting in thousands of curves, for maximum speed and quality on every welding job.

Transmission of Welding Current.—The welding current is conducted from the generator to the work by multi-strand copper cable well insulated. Usual direction of flow of welding current for bare or washed electrodes is from the generator to the work, to the elec-

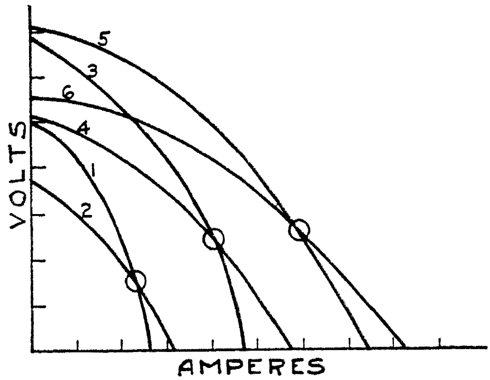

Fig. 13.

trode through the electrode holder, then through another cable to the machine. This is known as *straight* polarity (electrode negative). The accompanying drawing, Fig. 14 illustrates the welding circuit. When arc welding with *reversed* polarity, the cable to the work is nega-

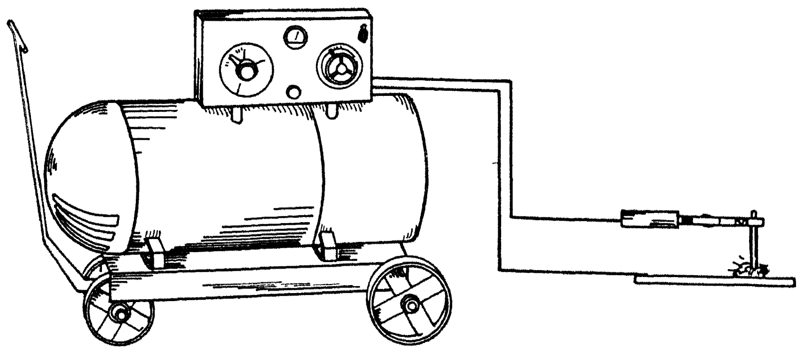

Fig. 14. The welding circuit.

tive; the electrode cable, positive. An extra flexible cable is used between the electrode holder and the welding machine. This cable is designed expressly for welding service and derives its high flexibility from its construction. It is made of thousands of very fine, almost hair-like, wires enclosed in a durable paper wrapping which allows the conductor to slip readily within its rubber insulation when cable is bent. The pure high-grade rubber insulation also contributes to flexibility. Wear resistance is provided this cable by an extra tough, braided cotton reinforcing and by the special composition and curing of the waterproof rubber covering which provides a smooth finish, highly resistant to abrasion. For grounding the welding circuit, a somewhat less flexible but equally wear resistant cable is used.

The size of the cables used in welding varies, being dependent upon the capacity of the machine and the distance of the work from the

machine. The size cable is selected carefully because of its definite bearing on weld production and efficiency. The following table indicates cable sizes for various lengths for different sized welding machines.

Machine Size in Amperes	Cable Sizes for Lengths		
	Up to 50′	50′ - 100′	100′ - 250′
100	2	2	2
200	2	1	2/0
300	0	2/0	4/0
400	2/0	3/0	4/0*
600	2/0	4/0	4/0*

*The longest length of 4/0 cable recommended for 400-ampere welder is 150′; for 600-ampere machine 100′. For greater distances, cable size is increased. The question of the longest cable practical to use is determined by considering the weld production, efficiency and ease of handling.

Electrode Holders.—An electrode holder is simply a clamping device for holding the electrode and is provided with a handle for the operator's hand. The welding current is conveyed through the electrode holder to the electrode. The clamping device should be so designed as to hold the electrode securely in position yet permit quick and easy change of electrodes, also providing good electrical contact. It should also be light in weight to permit ease of handling, yet sturdy enough to withstand rough usage. A popular type of electrode holder is illustrated in Fig 15.

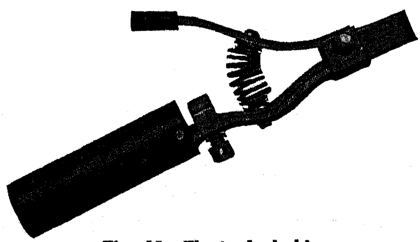

Fig. 15. Electrode holder.

ELECTRODES

The electrodes used in the electric arc welding processes may be either metal or carbon, depending upon the work to be welded and other requirements of the application.

Metallic Electrodes.—In manual welding the metallic electrode is generally used. Metallic electrodes are commercially manufactured in diameter sizes ranging from $\frac{1}{16}''$ to $\frac{3}{8}''$ and larger and usually

in lengths of 14″ and 18″. The proper size of electrode to use is determined by the requirements of the weld and material to be welded. The composition of the electrodes varies depending upon the type of work and composition of material to be welded.

Washed electrodes are those which are lightly coated with an arc stabilizing chemical such as lime. No attempt is made to prevent oxidation and no slag is formed on the bead. The coating merely serves to produce electrodes of more uniform arc characteristics than bare welding wire, but does not affect the characteristics of the deposited metal.

Semi-coated electrodes have a coating of appreciable thickness which usually contains a binder. In most cases this coating is applied by dipping. This coating not only serves to stabilize the arc but may in some cases partially control the oxidation of the molten metal as it is deposited by forming a thin film of slag over the surface of the bead. The coatings on this type of electrode may be of sufficient quantity to amount to 1% or 2% of the total weight of the electrode.

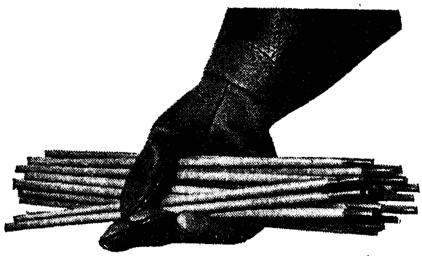

Fig. 16. Shielded arc type electrodes.

Heavily coated shielded-arc type electrodes utilize all the benefits of chemical coatings. These coatings may be applied to bare wire by dipping, extrusion or winding and may in weight amount to 10% or more of the total weight of the electrode. It is by the use of this type of coating that the arc characteristics and the physical and chemical properties of the deposited metal can be controlled. The coatings not only produce a protecting shield of non-oxidizing or reducing atmospheres around the arc but also control the (1) fluidity of the metal, (2) penetration, (3) shape of the beads, (4) physical properties of the deposit, and (5) may control the composition of the deposit by addition of various metals and alloys.

Carbon Electrodes.—For manual welding and cutting, carbon electrodes are manufactured in diameter sizes ranging from 5/32″ up to and including 1″ in 12″ lengths. The carbons are baked in the process of manufacture. For automatic welding with the shielded arc the carbons are manufactured in diameter sizes ranging from 3/16″ up to and including 1/2″. This type of carbon must be carefully gauged as to size and inspected for straightness.

PROTECTIVE EQUIPMENT

Head Shields and Face Shields.—To protect the operator's face and eyes from the direct rays of the arc, it is essential that a face shield or head shield be used. These shields are generally constructed of some kind of pressed fibre insulating material, dead black in color to reduce reflection. The shield should be light in weight and designed to insure greatest possible comfort to the welder or user.

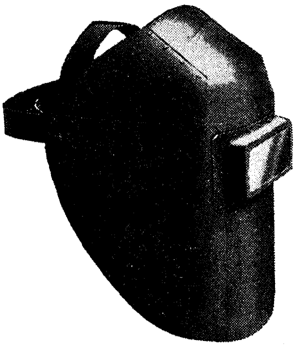

Fig. 17. Head shield.

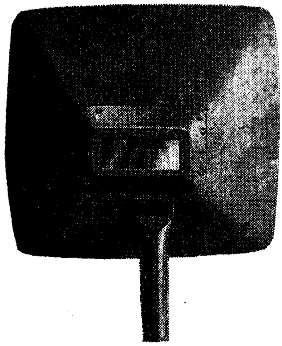

Fig. 18. Face shield.

Protective shields are provided with a glass window, the standard being 2″ x 4⅛″. The glass should be of such composition as to absorb the infra-red rays, the ultra violet rays and most visible rays emanating from the arc. In selecting welding lens, it is important to consider the manufacturer's reputation and his experience in the use of welding equipment as well as results of scientific tests of the lens. A welding lens, which is guaranteed to absorb 99.5% or more infra-red rays and 99.75% or more ultra violet rays, is available. This lens has been reported as absorbing 100% of these rays by actual tests by the U. S. Bureau of Standards.

The welding lens in the head or face shield is protected from molten metal splatter and breakage by a chemically-treated, clear "non-splatter" glass covering the exposed side of the lens.

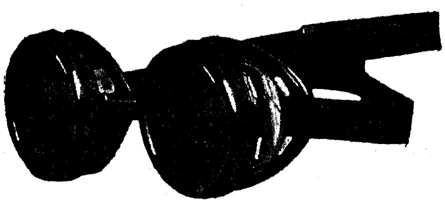

Fig. 19. Goggles.

Special goggles are used by welders' helpers, foremen, supervisors, inspectors and others working close to a welding arc to protect their

eyes from occasional flashes. A popular goggle has adjustable elastic headbands and is light, cool, well ventilated and comfortable. Clear cover glasses and greenish tint lenses in various shades are available for this goggle.

Aprons.—During the arc welding process some sparks and globules of molten metal are thrown out from the arc. For protection from possible burns it is advisable that the operator wear a leather or protective apron. Some operators also wear spats or leggings and sleevelets of leather or other fire-resisting material. Some sort of protection should be provided for the operator's ankles and feet, inasmuch as a globule of molten metal can cause a small but painful burn to the foot before it can be extracted from the shoe. Turn the pants down at the bottom so that molten metal will not fall in the cuffs.

Fig. 20. Chrome leather sleeve.

Fig. 21. Chrome leather glove.

Gloves.—A gauntlet type of glove, preferably of leather, is generally used by operators for protection of the hand from the arc rays, spatter of molten metal, sparks, etc. Gloves also provide protection when handling the work.

VENTILATION

Working conditions in the welding shop often can be improved for increased efficiency and lower costs by means of effective ventilation.

The most effective and economical type of ventilating equipment for welding operators is that which removes the smoke and heat of welding at its source—in other words, at the arc. This equipment consists of a motor-driven suction unit and a flexible metal suction tube through which the smoke and heat are drawn. The smoke is exhausted either into a filter at the power unit or out-of-doors. The intake of the suction tube is positioned in the vicinity of the welding arc so that it collects the majority of the smoke particles and much of the heat.

By removing the smoke at its source, this ventilator is much more effective and economical than the conventional system which moves air through the entire shop in order to remove the smoke admixture. In cold weather, the localized type of ventilator saves considerable heat because less air must be taken into the shop, heated and exhausted.

MISCELLANEOUS ACCESSORIES

As a means of protection to other workers from the arc rays, splatter of molten metal and sparks, the scene of each welding operation should be enclosed by either a portable or permanent structure, booth or screen. A form of welding booth is illustrated in Fig. 22. Where the welding machine must be taken to the work it is advisable to surround the scene of welding operation with portable screens painted dead black to prevent reflection of the arc rays.

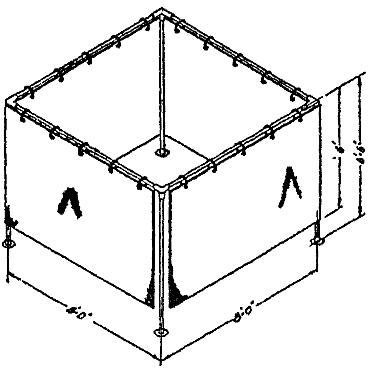

Fig. 22. Welding booth.

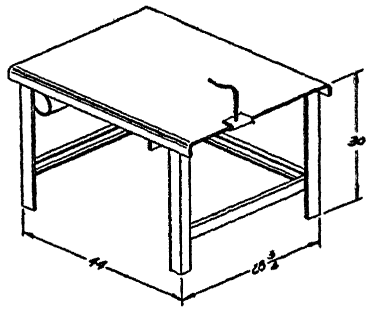

Fig. 23. Welding table.

The majority of welding operations require the use of a table or bench. Every operator has his own idea of the proper type of welding table. However, the one shown in Fig. 23 has proved very practical. As the table illustrated indicates, a suitable and well insulated container for electrodes should be provided, also an insulated hook for supporting the electrode holder when not in use.

Other tools which will prove of value in any shop where welding is done include wire brushes for cleaning the welds, cold cuts for chipping, clamps for holding work in position for welding, also wedges; and where work is large or heavy, a crane or chain block. A drill, air hammer and grinder are also of value.

PART II

TECHNIQUE OF WELDING

PART II

TECHNIQUE OF WELDING

When an arc is drawn between the work or base metal and the electrode, the base metal in the path of the arc stream is melted, forming a pool of molten metal. The molten metal seems to be forced out of the pool by the blast from the arc. A small depression in the base metal is thus formed and molten metal is piled up around the edges of this depression, which is known as the arc crater, see Fig. 24. The depth of the crater serves as an indication of the penetration obtained by the welding process, and also indicates to a certain

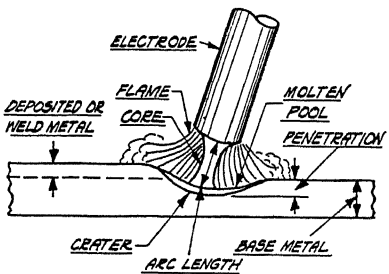

Fig. 24. Diagrammatic sketch of an ordinary arc in process of welding.

extent the soundness of the weld. The depth of the arc crater depends generally upon the current and voltage of the arc. It should in general never be less than 1/16″ deep.

Length of Arc.—Arc length is the distance between the end of the electrode and the surface upon which the molten globules are deposited. The correct length of the arc will vary, depending upon the size *and type* of electrodes used, the material to be welded and amount of welding heat, and other regulating factors involved in the *welding process employed.* The ordinary or unshielded arc should be short for best results. An important reason for this is that the globules of molten electrode metal in process of deposition may have the smallest possible opportunity to contact with the ambient atmosphere and from it absorb a minimum of oxygen and nitrogen. *The above instructions do not apply when welding with a shielded arc.* It has been found that the correct length of the shielded arc is longer. The heavy coating of the electrodes employed with the shielded arc is not consumed as rapidly as the electrode metal melts. The resultant projection of coating focuses a concentrated arc stream though the actual length of the arc is longer.

Arc Blow.—When the arc stream tends to waver from its intended path, the action is known as arc blow. During the welding process there is current flowing through the electrode, through the arc stream and through the base metal. This current sets up magnetic fields around the electrode, the arc stream and the base metal. The combination of the action of these magnetic fields or fluxes on the arc stream may under certain conditions pull the arc stream out

of its intended path. The action of this magnetic phenomenon generally can be corrected either by welding away from the ground, changing the position of the electrode in relation to the work, changing the relation of the ground on the work or, in cases where the work is placed on a grounded support by changing the position of the work. In some cases, the magnetic condition is improved by giving one of the cable leads a few turns around a part of the work being welded such as an I-beam in a machine base, etc. There is no general rule for overcoming arc blow but in almost every case experimentation by the above methods will put the arc stream under control.

Preparation of the Work.—The work to be welded should be clean, preferably free from corrosion, oil, water and other foreign matter. To facilitate welding, the work should be placed where possible in such a position so that flat welds can be made. Next preferable is the position requiring vertical or overhead welds. Work in a position requiring horizontal welds is least preferable, because welds in this location require more time and care in their making; but the physical qualities of such welds are equal to those made in other positions.

Preparation of the joint has an important bearing on the cost of welding and it is suggested that the reader study carefully the section on Costs (Page 205).

WELDING TERMS

Many of the terms used in welding have been standardized by the American Welding Society.

These terms are given through the courtesy of the American Welding Society.

Actual Throat: See Throat of Fillet Weld. See Fig. 64.

All Weld Metal Test Specimen: A test specimen composed wholly of weld metal

Anode Drop: The voltage between the arc stream and the positive electrode.

Arc Brazing: An electric brazing process wherein the heat is obtained from an electric arc, formed between the base metal and an electrode, or between two electrodes.

Arc-Stream Voltage: The voltage across the gaseous zone which varies with the length of the arc.

Arc Welding: A non-pressure (fusion) welding process wherein the welding heat is obtained from an electric arc formed either between the base metal and an electrode, or between two electrodes.

Atomic Hydrogen Welding: An alternating current arc welding process wherein the welding heat is obtained from an arc produced between two suitable electrodes in an atmosphere of hydrogen.

Automatic Welding: Welding with equipment which automatically controls the entire welding operation. (Including feed, speed, oscillation, interruption, etc.)

Axis of a Weld: A line through the weld parallel to the root. See Fig. 25.

Back-Step Welding: A welding technique wherein the increments of weld metal are deposited opposite to the direction of progression.

Backing Strip: Material (metal, asbestos, carbon, etc.) backing up the root of the weld.

Bare Electrode: (Lightly coated). A solid metal electrode with no coating other than that incidental to the manufacture of the electrode, or with a light coating.

Base Metal:—(Parent Metal): The metal to be welded, or cut.

Base Metal Test Specimen: A test specimen composed wholly of base metal.

Bead Weld: A type of weld made by one passage of electrode or rod. See Figs. 41, 69 and 70.

TABULATION OF POSITIONS OF WELDS

Position	Inclination of Axis	Rotation of Face
Overhead	0°–60°	300°– 60°
Horizontal	0°–30°	{ 60°–150° 210°–300°
Flat	0°–30°	150°–210°
Vertical	{ 30°–60° 60°–90°	60°–300° 0°–360°

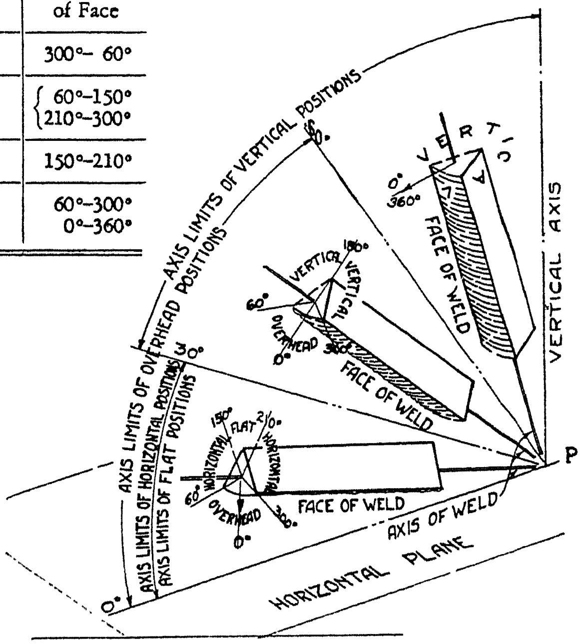

Fig. 25. Position of welds.

The horizontal reference plane is taken to lie always below the weld under consideration.

Inclination of axis is measured from the horizontal reference plane toward the vertical.

Angle of rotation of face is measured from a line perpendicular to the axis of the weld and lying in a vertical plane containing this axis. The reference position of rotation of the face invariably points in the direction opposite to that in which the axis angle increases. The angle of rotation of the face of weld is measured in a clockwise direction from this reference position when looking toward point "P".

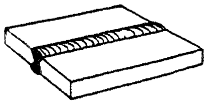

Fig. 26. Butt joint.

Types of welds applicable to butt joints

Square groove
Single-V groove
Double-V groove (illustrated)
Single bevel groove
Double bevel groove
Single-U groove
Double-U groove
Single-J groove
Double-J groove
Butt (resistance)

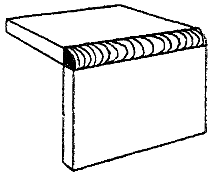

Fig. 27. Corner joint.

Types of welds applicable to corner joints

Fillet (illustrated)
Square groove
Single-V groove
Single bevel groove
Double bevel groove
Single-U groove
Single-J groove
Double-J groove
Projection (resistance)

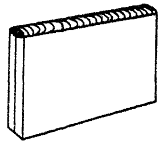

Fig. 28. Edge joint.

Types of welds applicable to edge joints

Bead (illustrated)
Single-V groove
Single-U groove

Beading (Parallel Beads): A technique of depositing weld metal without oscillation of the electrode. See Fig. 69.

Bend Test: See Free Bend Test and Guided Bend Test.

Bevel Angle: See Groove Angle, Fig. 56.

Bevel Weld: See Groove Weld.

Bond: The junction of the weld metal and the base metal.

Brazing: A group of welding processes wherein the filler metal is a non-ferrous metal or alloy whose melting point is higher than 1000° F. but is lower than that of the metals or alloys to be joined.

Butt Joint: See Fig. 2.

Carbon Arc Cutting: The process of severing metals by melting with the heat of the carbon arc.

Carbon Arc Welding: An arc welding process wherein a carbon or graphite electrode is used, with or without the use of filler metal.

Carbon Electrode: See Electrode.

Chain Intermittent Fillet Welds: See Fig. 44.

Closed Joints: See Root Opening.

Coated Electrode: See Covered Electrodes.

Composite Electrode: An electrode with or without a flux having more than one filler material combined mechanically.

Composite Joint: A joint wherein welding is used in conjunction with a mechanical joint.

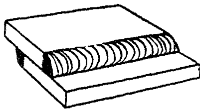

Fig. 29. Lap joint.

Types of welds applicable to lap joints

Fillet (illustrated)
Plug
Slot
Spot (resistance)
Seam (resistance)
Projection (resistance)

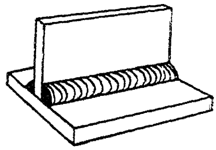

Fig. 30. Tee joint.

Types of welds applicable to tee joints

Fillet (illustrated)
Single bevel groove
Double bevel groove
Single-J groove
Doube-J groove

Concave Fillet Weld: See Size of Fillet Weld. See Fig. 65.

Concurrent Heating: Supplementary heat applied to a structure during the course of welding.

Contact Jaw: An electrical terminal used in a resistance butt-welding machine to securely clamp the parts to be welded and conduct the electric current to these parts.

Continuous Weld: A weld which extends uninterruptedly for its entire length.

Convex Fillet Weld: See Size of Fillet Weld. See Fig. 65.

Convexity Ratio: See Fig. 71.

Corner Joint: See Fig. 27

Covered (Shielded Arc) Electrode: A metal electrode which has a relatively thick covering material serving the dual purpose of stabilizing the arc and improving the properties of the weld metal.

Cover Glass: A clear glass used to protect the lens in goggles, face shields and helmets from spattering material.

Crater: A depression at the termination of an arc weld.

Deposited Metal: Metal that has been added by a welding process.

Deposition Efficiency: The ratio of the weight of deposited metal to the net weight of the electrodes consumed *(exclusive of stubs)*.

Depth of Fusion: The depth of fusion of a groove weld is the distance from the original surface of the base metal to that point within the joint at which fusion ceases.

Direct Current Arc Welding: An arc-welding process wherein the power supply at the arc is direct current.

Double Groove Welds: See Groove Welds.

Edge Joint: See Fig. 28.

Edge Preparation: See Fig. 50.

Effective Length of Weld: The length of the correctly proportioned cross section of a weld.

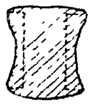
Fig. 31. Square groove weld.

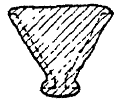
Fig. 32. Single-V groove weld.

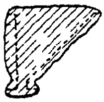
Fig. 33. Single bevel groove weld.

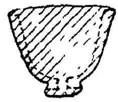
Fig. 34. Single-U groove weld.

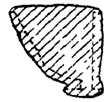
Fig. 35. Single-J groove weld.

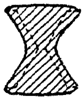
Fig. 36. Double-V groove weld.

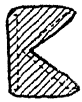
Fig. 37. Double bevel groove weld.

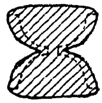
Fig. 38. Double-U groove weld.

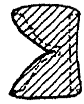
Fig. 39. Double-J groove weld.

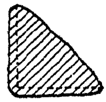
Fig. 40. Fillet weld.

Electric Brazing: A group of brazing processes wherein the heat is obtained from electric current.

Electrode:
- A. Metal Arc Welding: Filler metal in the form of a wire or rod, either bare or covered, through which current is conducted between the electrode holder and the arc.
- B. Carbon Arc: A carbon or graphite rod through which current is conducted between the electrode holder and the arc.
- C. Atomic Hydrogen: One of two tungsten rods between the points of which the arc is maintained.
- D. Resistance Welding: A bar, wheel or die through which the current is conducted and the pressure applied to the work


Fig. 41. Bead weld.

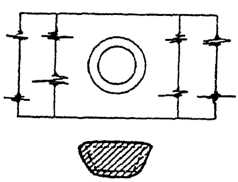
Fig. 42. Plug weld.

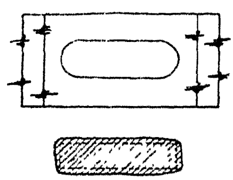
Fig. 43. Slot weld.

Electrode Holder: A device used for mechanically holding the electrode.

Electrode Tip (Point): A replaceable tip of metal on an electrode having the electrical and physical characteristics required for spot and projection welding.

Face (Hand) Shield: See Hand (Face) Shield.

Face of Weld: See Fig. 59.

Filler Metal: Material to be added in making a weld.

Fillet Weld: See Fig. 40.

Fillet Weld Size: See Size.

Filter Lens: A glass used in goggles, helmets and shields to exclude harmful light rays.

Flash Butt Welding: A resistance butt welding process wherein the potential is applied before the parts are brought in contact and where the heat is derived principally from a series of arcs between the parts being welded.

Flash (Fin): Metal expelled from a joint made by the resistance welding process.

Flat Position of Welding (Downhand): See Fig. 25.

Flush Weld: A weld made with a minimum reinforcement.

Flux: A fusible material or gas used to dissolve and/or prevent the formation of oxides, nitrides or other undesirable inclusions formed in welding.

Forge Welding (Blacksmith, Roll, Hammer): A group of pressure welding processes wherein the parts to be welded are brought to suitable temperature by means of external heating and the weld is consummated by pressure or blows.

Free Bend TEST Specimen: A bending test wherein the specimen is bent without constraint of a jig.

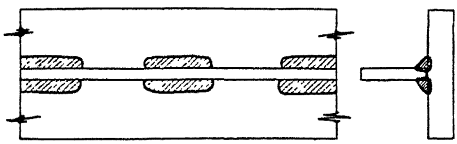

Fig. 44. Chain intermittent fillet welds.

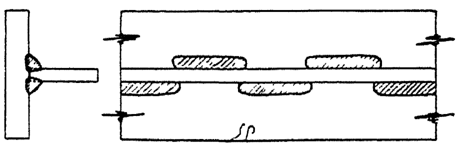

Fig. 45. Staggered intermittent fillet welds.

Fusion Welding: A group of welding processes in which metals brought to the molten state at the surfaces to be joined are welded with or without the addition of filler metal and without the application of mechanical pressure or blows.

Gas Cutting: The process of severing ferrous metals by means of the chemical action of oxygen on elements in the base metal.

Gas Pocket (Blow-Hole): A cavity in a weld caused by gas inclusion.

Gas Welding: A non-pressure (fusion) welding process wherein the welding heat is obtained from a gas flame.

Groove: See Fig. 51.

Groove Angle: See Fig. 56.

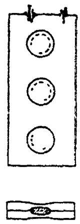

Fig. 46. Spot weld.

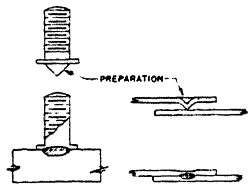

Fig. 47. Projection welds.

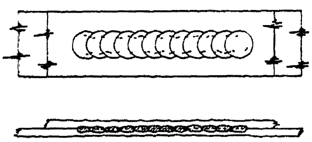

Fig. 48. Seam weld.

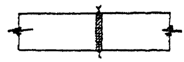

Fig. 49. Flash (butt) weld.

Groove Welds: (a) Square Groove Weld: See Fig. 31.
(b) Single-Vee Groove Weld: See Fig. 32.
(c) Single Bevel Groove Weld: See Fig. 33.
(d) Single-U Groove Weld: See Fig. 34.
(e) Single-J Groove Weld: See Fig. 35.
(f) Double-Vee Groove Weld: See Fig. 36.
(g) Double Bevel Groove Weld: See Fig. 37.
(h) Double-U Groove Weld: See Fig. 38.
(i) Double-J Groove Weld: See Fig. 39.

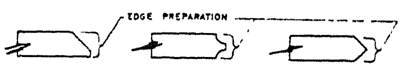

Fig. 50. Edge preparation.

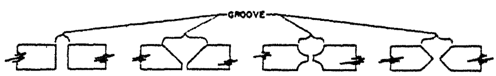

Fig. 51. Groove.

Ground Connections: See Welding Ground.

Guided Bend Test: A bending test wherein the specimen is bent to a definite shape by means of a jig.

Hammer Welding: See Forge Welding.

Hand (Face) Shield: A protective device used in arc welding for shielding the face and neck, equipped with suitable filter glass lens and designed to be held by hand.

Heat-Affected Zone: The portion of the base metal whose structure or properties has been altered by the heat of welding.

Helmet Shield: A protective device used in arc welding for shielding the face and neck, equipped with suitable filter glass lens and designed to be worn on the head.

Horizontal Position of Welding: See Fig. 25.

Included Angle: See Fig. 57.

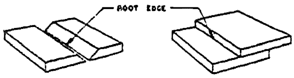

Fig. 52. Root edge.

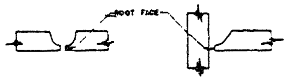

Fig. 53. Root face.

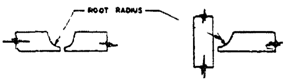

Fig. 54. Root radius.

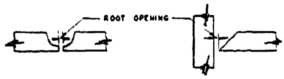

Fig. 55. Root opening.

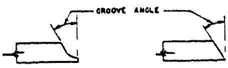

Fig. 56. Groove angle.

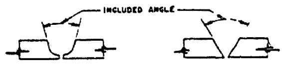

Fig. 57. Included angle.

Intermittent Weld: A weld whose continuity is broken by unwelded spaces.

J Groove Welds: See Groove Welds.

Kerf: The space from which the metal has been removed by a cutting process.

Lap Joint: See Fig. 29.

Layer: See Fig. 68.

Leg of Fillet Weld: See Fig. 63.

Lens: See Filter Lens.

Manual Weld: A weld made by an operator unaided by mechanically or electrically controlled equipment.

Melting Rate: The weight of electrode consumed in a unit of time.

Melting Ratio: The ratio of the volume of weld metal below the original surface of the base metal to the total volume of the weld metal.

Metal Arc Cutting: The process of severing metals by melting with the heat of the metal arc.

Metal Arc Welding: An arc welding process wherein the electrode supplies the filler metal in the weld.

Metal Electrode: See Electrode.

Non-Pressure Welding: A group of welding processes wherein the weld is made without pressure.

Open Joints: See Root Opening.

Overhead Position of Welding: See Fig. 25.

Overlap (Roll): Protrusion of weld metal at the toe of a weld beyond the limits of fusion.

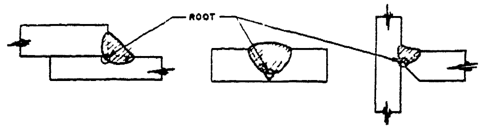

Fig. 58. Root of weld.

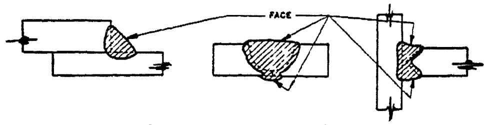

Fig. 59. Face of weld.

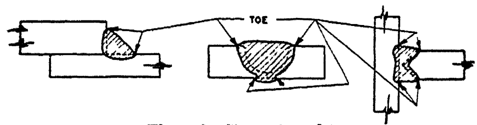

Fig. 60. Toe of weld.

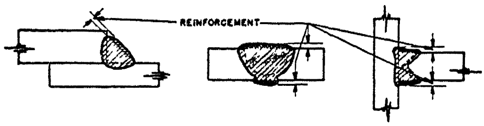

Fig. 61. Reinforcement of weld.

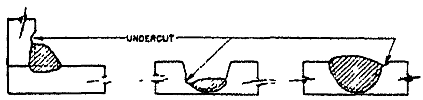

Fig. 62. Undercutting.

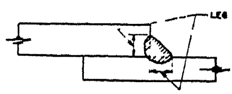

Fig. 63. Leg of fillet weld.

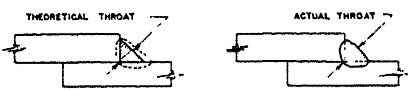

Fig. 64. Throat of fillet weld.

Pad: See Fig. 67.

Peening: Mechanical working of metal by means of hammer blows.

Penetration (Depth of Fusion): See Fig. 66.

Percussive Welding: A resistance welding process utilizing stored up electrical energy suddenly discharged.

Plain Thermit: A mixture of iron oxide and finely divided aluminum.

Plug Weld: See Fig. 42.

Poke Welding: A spot welding process wherein pressure is applied manually to one electrode only.

Porosity: A multiplicity of gas pockets or inclusions.

Positions of Welds: See Fig. 25.

Post Heating: Heat applied to base metal subsequent to welding or cutting.

Preheating: Heat applied to base metal prior to welding or cutting.

Pressure Welding: A group of welding processes wherein the weld is consummated by pressure.

Projection Weld: See Fig. 47.

Projection Welding: A resistance welding process wherein localization of heat between two surfaces or between the end of one member and surface of another is effected by projections.

Rate of Deposition: The weight of weld metal deposited in a unit of time.

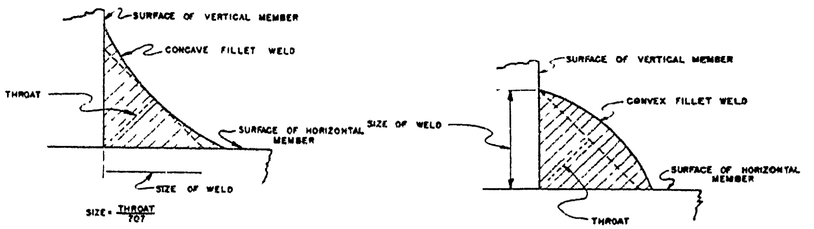

Fig. 65. Size of fillet weld.

Note: The size of a fillet weld is the leg length of the largest inscribed right isosceles triangle.

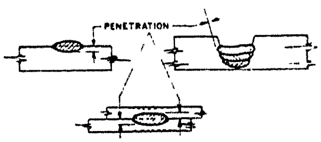

Fig. 66. Penetration.

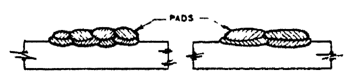

Fig. 67. Pads.

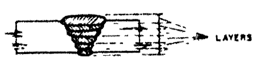

Fig. 68. Layers.

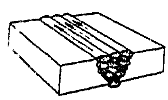

Fig. 69. Beading.

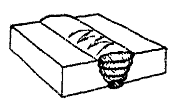

Fig. 70. Weaving.

Reinforcement of Weld: See Fig. 61.

Residual Stress: Stresses remaining in a structure or member as a result of thermal or mechanical treatment, or both.

Resistance Butt Weld: See Fig. 49.

Resistance Butt Welding: A group of resistance welding processes wherein the fusion occurs simultaneously over the entire contact area of the parts being joined.

Resistance Flash Butt Welding: See Flash Butt Welding.

Resistance Welding: A pressure welding process wherein the heat is obtained from the resistance to the flow of an electric current.

Reversed Polarity: The arrangement of arc welding leads wherein the work is the negative pole and the electrode is the positive pole in the arc circuit.

Root Edge: See Fig 52.

Root Face (Shoulder): See Fig. 53.

Root Opening: See Fig. 55.

Root of Weld: See Fig. 58.

Root Radius: See Fig. 54.

Seal Weld (Seal Bead): A weld used to obtain tightness.

Seam Weld: See Fig. 48.

Seam Welding: A resistance welding process wherein overlapping or tangent spot welds are made progressively.

Semi-Automatic Metal Arc Weld: A weld made with equipment which automatically controls the feed of the electrode — the manipulation of the electrode being controlled by hand.

Shielded Carbon Arc Welding: A carbon arc welding process wherein the arc and molten weld metal are protected from the atmosphere by a shielding medium.

Shielded Metal Arc Welding: A metal arc welding process wherein the arc and weld metal is protected from the atmosphere by a shielding medium.

Shoulder: See Root Face.

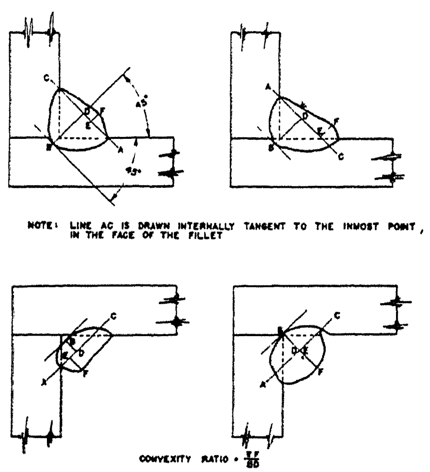

Fig. 71. Convexity ratio.

Single-Groove Welds: See Groove Welds.

Size:

(a) Fillet Weld: The size of a fillet weld is the leg length of the largest inscribed isosceles right triangle. See Fig. 65.

(b) Groove Weld: The size of a groove weld is the depth of the groove. Where depth of fusion materially exceeds the groove depth, the size of the weld is the depth of fusion.

Slag Inclusion: Non-metallic material entrapped in a weld.

Slot Weld: See Fig. 43.

Spatter Loss: The difference in weight between the amount of electrode deposited and the weight of the electrode consumed (melted).

Spot Weld: See Fig. 46.

Spot Welding: A resistance welding process wherein the fusion is confined to a relatively small portion of the area of the lapped parts to be joined.

Square Groove Weld: See Groove Welds.

Staggered Intermittent Fillet Welds: See Fig. 45.

Straight Polarity: The arrangement of arc welding leads wherein the work is the positive pole and the electrode is the negative pole of the arc circuit.

Stress Relief Heat Treatment:* Uniform heating of structures to a sufficient temperature below the critical range, to relieve the major portion of the residual stresses, followed by uniform cooling.

Tack Weld: A weld used for assembly purposes only.

Tee Joint: See Fig. 30.

Theoretical Throat: See Throat of Fillet Weld. See Fig. 64.

Thermal Stress: The stresses produced in a structure or member caused by differences in temperature or coefficients of expansion.

Thermit Reaction: A chemical reaction between iron oxide and aluminum which produces a highly superheated liquid iron and aluminum oxide slag.

Thermit Welding: A non-pressure (fusion) welding process wherein the heat is obtained from liquid steel produced by a thermit reaction, and the filler metal is supplied by the steel produced in this reaction.

Throat of Fillet Weld: See Fig. 64.

Toe of Weld: See Fig. 60.

Types of Welds: See "Bead," "Fillet," "Plug," "Slot," and "Groove" Welds.

U Groove Welds: See Grove Welds.

Unaffected Zone: That portion of the base metal outside of the heat-affected zone wherein no change in physical properties and/or structure has taken place.

Undercut: See Fig. 62.

Unshielded Carbon Arc Welding: A carbon arc welding process wherein no shielding medium is used.

Vertical Position of Welding: See Fig. 25.

Weaving: A technique of depositing weld metal in which the electrode is oscillated at right angles to the direction of travel. See Fig. 70.

Weld: A localized consolidation of metals by a welding process.

Welded Joint: A localized union of two parts by welding.

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*Note: Terms normalizing, annealing, etc., are misnomers for this application.

Weldment: An assembly whose component parts are joined by welding.

Weld Metal: The metal resulting from the fusion of the filler and base metals.

Weld Penetration: See Fig. 66.

Welding Ground: The side of the circuit opposite the welding electrode.

Welding Leads: Conductors furnishing an electrical path between source of welding power and electrodes.

Welding Rod: Filler metal, in wire or rod form, used in the gas welding process and those arc welding processes wherein the electrode does not furnish the metal.

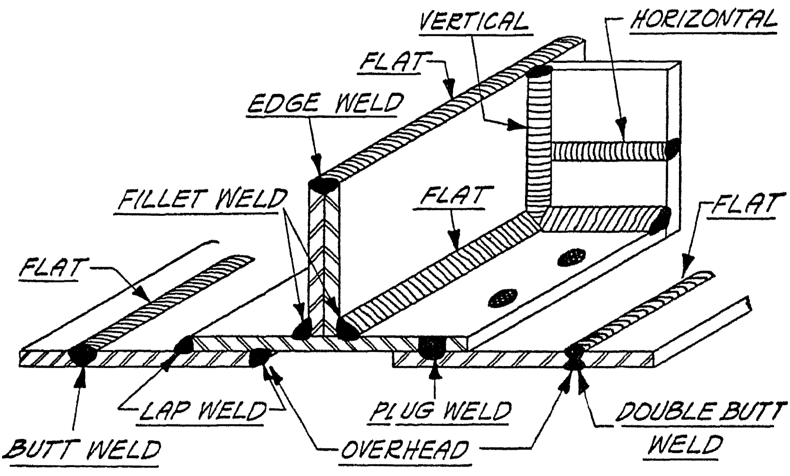


Fig. 72. Examples of welds and locations.

Selection of Type of Joint.—The selection of the type of joint to use in a particular application is governed by three factors:

1. The load and its characteristics, that is, whether the load is in tension or compression, and whether bending, fatigue or impact stresses in any combination are present.
2. The manner in which the load is applied, that is, whether load application is steady, variable or sudden.
3. The cost of the joint preparation and welding.

Obviously the joint to select is the one which meets the load requirements and costs the least.

Aid in selecting the best joint for given service conditions and cost is provided in the following detailed discussion of the principal types of joints.

Butt joints are of several types, each having a number of variations. However, the general classification lists butt joints as square, vee bevel, U and J.

The *square butt joint* Fig. 73, is suitable for all usual loads and requires full and complete fusion, particularly when load is of fatigue or intermittent nature. The base metal for this type of joint must be good weldable steel since a large portion of the base metal is melted during welding. The thickness of plate on which the *square butt joint* is used is generally 3/8" or lighter when welded with metal electrode and 3/4" or lighter with carbon electrode, although this type of joint has been used on other plate sizes. Preparation for welding this joint is simple, requiring only a matching of the edges of the plate, separated by a distance dependent upon the plate thickness. Because of the simple preparation, the *square butt joint* is low in cost.

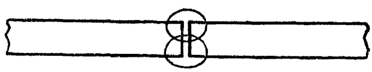


Fig. 73. Square butt joint.

The *single vee butt joint,* Fig. 74, is suitable for all usual load conditions. It is generally used with plate thickness considerably greater than the *square butt joint*—3/8" or heavier—although its use on thinner plate is not unusual. Preparation is more costly than the *square butt joint* and more electrode is used in welding.

The *double vee butt joint,* Fig. 75, is suitable for all usual load conditions. It is used for plates of greater thickness than the *single vee* and for work which can be welded from both sides. Cost of preparation for welding is higher than for *single vee butt joint* but *double vee* requires approximately half as much electrode. Cost of machining should be weighed against the cost of welding and the joint selection made accordingly.

Fig. 74. Single vee butt joint.

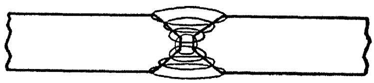


Fig. 75. Double vee butt joint.

The *single U butt joint,* Fig. 76, is suitable for all usual load conditions and is used for work of the highest quality. Replaces *single* or *double vee joint* for joining plates 1/2" to 3/4" thick although it is also used on heavier plate. For plates of this thickness, *single* or *double vee* would require a considerable amount of weld metal. Machining the plates to a *single U* reduces amount of weld metal needed but increases machining costs. The joint is welded from one side except for a single bead which is put in last on opposite side from the U.

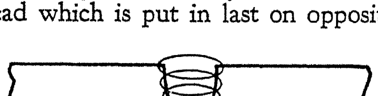


Fig. 76. Single U butt joint.

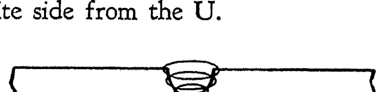


Fig. 77. Double U butt joint.

The *double U butt joint,* Fig. 77, is suitable for all load conditions and is used for welding heavy plates—3/4" and thicker—where the

welding can be done from both sides. This joint requires less weld metal than the *single U* but costs more to machine. Choice between *double U* and *double vee* should be made by comparing the machining and welding costs of the two, then selecting the joint which costs less.

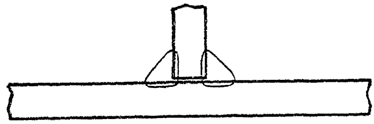


Fig. 78. Square tee joint.

The *square tee joint*, Fig. 78, corresponds to the *square butt joint* in that no machining of plates is required. The *square tee* is used for all ordinary plate thicknesses, principally for loads which place the welds in longitudinal shear. For severe impact or heavy transverse loads, the non-uniform stress distribution of the joint should be kept in mind and the stress intensity of the application duly considered. The *square tee* requires more weld metal and therefore has higher welding cost than other types of *tee joints*.

The *single bevel tee joint*, Fig. 79, is suitable for much more severe loads than the *square tee*, due to its better distribution of stress. It is employed, in most instances, for welding plates ½" or thinner in work which can be welded from one side only. While more costly to machine than the *plain tee*, the *single bevel tee joint* is lower in electrode costs.

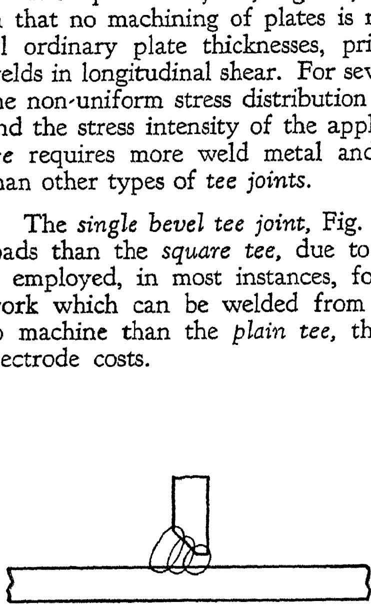


Fig. 79. Single bevel tee joint.

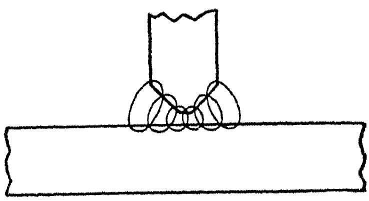


Fig. 80. Double bevel tee joint.

The *double bevel tee joint*, Fig. 80, is suitable for heavy loads in longitudinal or transverse shear in joining heavy plate where welding can be done from both sides. *Double bevel* is somewhat higher than *single bevel tee joint* in machining cost, but has lower electrode cost than some other types such as *plain tee*.

The *single J tee joint*, Fig. 81, is suitable for severe loads, and while it may be used for usual size plates, is generally applied to plates 1" and heavier. The welding is done from one side only. However, it is advisable to put in a final finish bead on the side opposite the J. Although somewhat more costly to machine than the *single vee*, the *single J tee joint* is lower in electrode cost.

The *double J tee joint,* Fig. 82, is suitable for exceedingly severe loads of all types in heavy plate—$1\frac{1}{2}''$ and heavier—where welding can be done from both sides. Although the machining costs for the *double J tee* are higher than for other types of *tee joints,* less electrode is required, consequently the cost per joint is reduced.

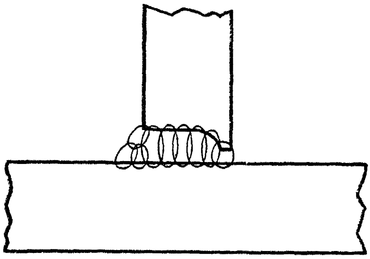


Fig. 81. Single J tee joint.

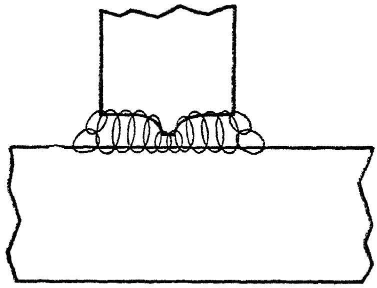


Fig. 82. Double J tee joint.

The *single fillet lap joint,* Fig. 83, is frequently used and has the advantage of requiring practically no machining to fit the edges of the plate. When fatigue or impact loads are encountered, stress distribution should be carefully studied. Where loading is not too severe, the *single fillet lap joint* is suitable for welding plate of all thicknesses.

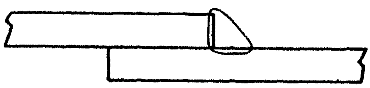


Fig. 83. Single fillet lap joint.

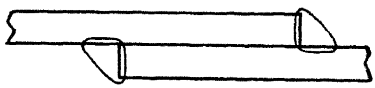


Fig. 84. Double fillet lap joint.

The *double fillet lap joint,* Fig. 84, is suitable for load conditions much more severe than can be met by the *single fillet lap joint.* In general, the two fillets should be full size, although one fillet may be smaller than the other in some instances. Because of its lower cost, the *double fillet lap joint* is widely used. For extremely severe loads, the butt joint, Figs. 73 to 77, should be used.

The *flush corner joint,* Fig. 85, is suitable where loads are not severe, or in welding plate 12-ga. and lighter. Although permissible for use on heavier plates care should be taken that loading is not excessive.

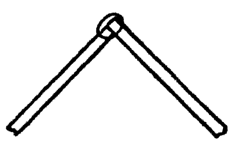


Fig. 85. Flush corner joint.

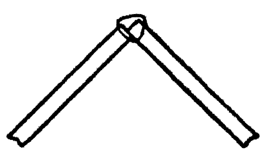


Fig. 86. Half-open corner joint.

The *half open corner joint,* Fig. 86, is suitable for loads where fatigue or impact are not severe. This joint is generally used on plates heavier than 12-ga. where the welding can be done from one side only. The

"shouldering" effect of this type of joint aids welding by reducing the tendency to burn through the plates at the corner.

The *full-open corner joint,* Fig. 87, is suitable for severe loads in welding plate of all thicknesses where the welding can be done from both sides. When properly made, this joint is of such shape as to provide good stress distribution, thus permitting its application to fatigue or impact loads of all types.

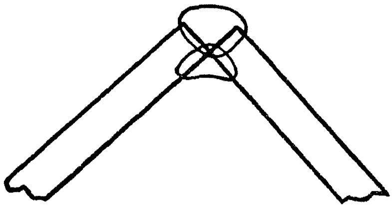


Fig. 87. Full-open corner joint.

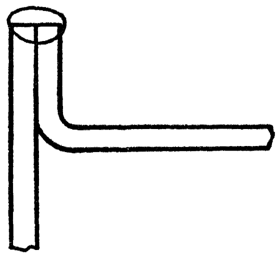


Fig. 88. Edge joint.

The *edge joint,* Fig. 88, is used in joining plates $\frac{1}{4}''$ or thinner for light loads. Careful consideration must be given to the load conditions, especially impact and fatigue, as this type of joint is not suitable for severe loads.

WELDING SYMBOLS AND INSTRUCTIONS FOR THEIR USE

Courtesy of The AMERICAN WELDING SOCIETY.

The specification example shown on Page 51 is given through the courtesy of Carnegie-Illinois Steel Corp.

Introduction

Welding cannot take its proper place as an engineering tool unless means are provided for conveying the information from the designer to the workmen. When structures are to be welded, simple and specific means must be used to convey the ideas of the designer to the shop. Such practices as writing "To be welded throughout" or "To be completely welded" on the bottom of a drawing, in effect, transfer the design of all attachments and connections from the designer to the welding operator, who cannot be expected to know what strength is necessary. This practice is *costly,* for certain shops, in their desire to be safe, use much more welding than is necessary.

These symbols provide the means of placing complete welding information on drawings. Even though the legends, numerical data and the instructions involve a considerable mass of material, nevertheless the successful use of the scheme depends so little on the memory, that hardly more than one reading of the instructions is necessary to obtain a working understanding of the system.

In practice many companies will probably need only a few of the symbols. If they desire, can make up their own legends to suit themselves, selecting such parts of the scheme as fit their needs. If this is done universally, we shall all be speaking the same language even though some use but a few of the symbols contained herein.

It will be seen from Fig. 89 that the symbols are ideographic; that is, they are picture-writing symbols; they show graphically the type of weld required. The individual basic symbols become the building blocks with which compound symbols to indicate complicated welded joints composed of many welds, can be constructed. Every weld in the joint must be shown.

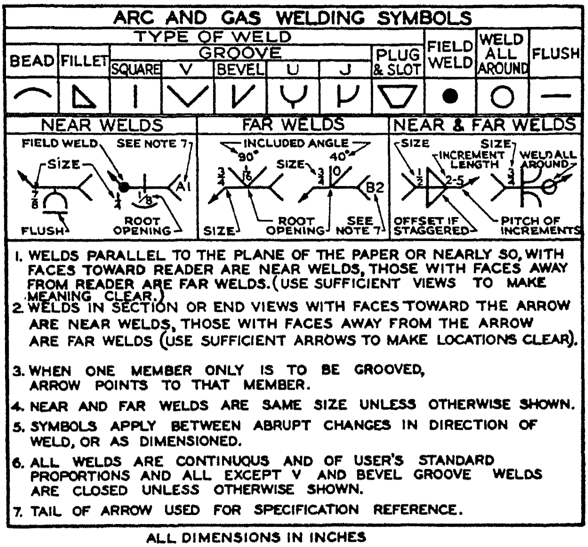


Fig. 89. Legend for use on drawings specifying arc welding.

The use of the words "far side", "near side", etc. in the past has led to confusion because it was often not clear as to whether "side" referred to member, joint or weld. In this scheme the facing of the weld in space is used as the criterion as to whether the weld is "near" or "far", and the use of the symbols has been greatly simplified.

Near and far welds are defined in notes 1 and 2 of Fig. 89 and the interpretations of these definitions are shown graphically in Figs. 90 to 93 inclusive. It will be seen that the facing quickly shows whether or not the symbol is applicable to that view. If not, the welding must be shown in other views.

The distinction between the symbols for the V- and bevel-grooved welds and the U- and J-grooved welds is not great. The draftsman should take sufficient care in the making of these particular symbols so that they do not become confused with each other.

The field weld symbol is the black dot used by the structural industry to indicate field riveting. In the case of work actually erected

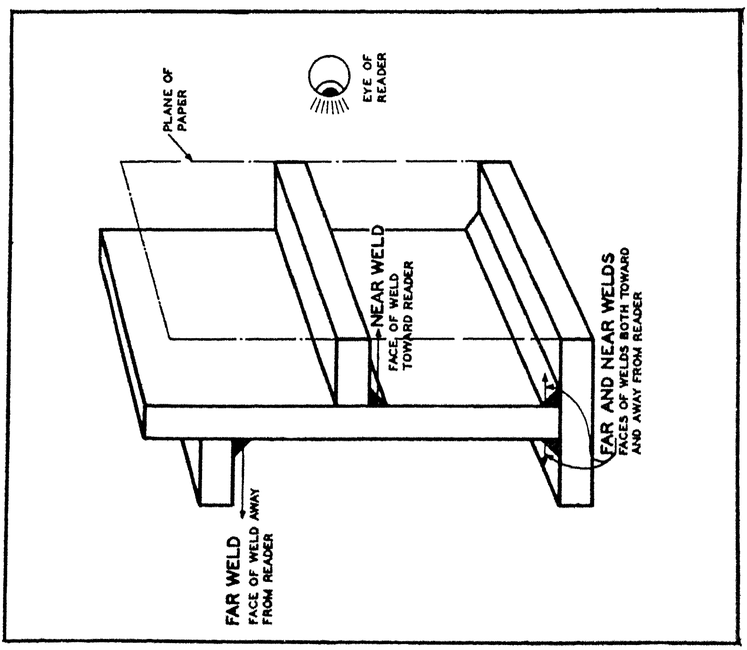


Fig. 90. Facing of fillet welds parallel to plane of paper.

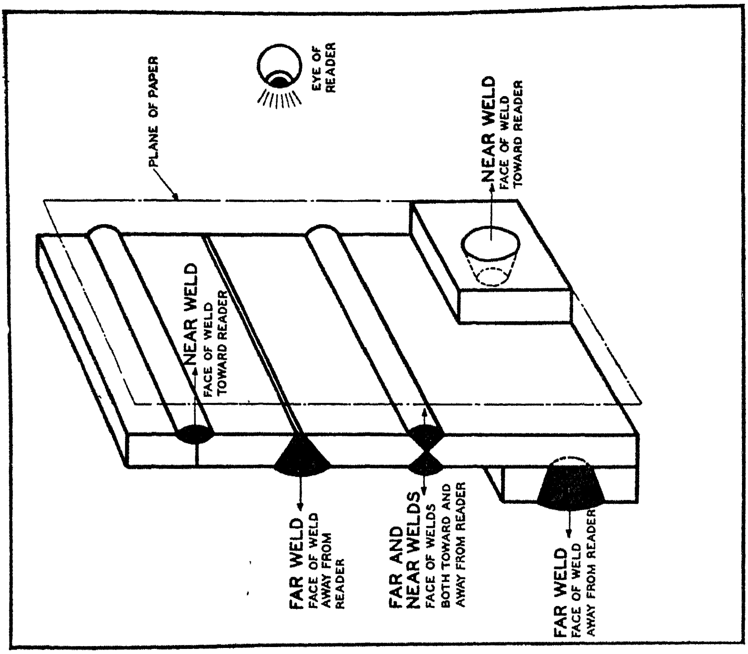


Fig. 91. Facing of groove and plug welds parallel to plane of paper.

in the field, just what constitutes field welding is simple. In the case of work done in the shop, yet done in the actual erection of the final product, the case is not so simple. An illustration of this obtains when work is done in the shop on an assembly line, such as is used in the automobile or car building industries. In this case, the individual user must decide for himself whether such erection welding is shop welding or field welding.

Appropriate finish marks have been found to be necessary, however, recommendations as to what finish marks shall be used are not strictly within the province of the Committee. As soon as the American Standards Association has definitely decided upon a system of finish symbols, it will be desirable for all concerned to adopt this system. In the meantime, however, a suggestion with regard to finish marks is made. It will be noted in Section IV of the Instructions that these finish marks merely suggest the means of finishing; that is, whether chipping, grinding or machining be used, and not the degree; they do not say whether a weld is to be rough or finish machined, rough or smooth ground, etc. Any such fine distinction must be made in the user's standard manner until such time as a national standard is established.

The location of the Symbols, numerical and other data on the reference line always has definite significance. This is depicted in Fig. 94 in which the standard manner of placing information on the Symbols is shown diagrammatically. Particular attention should be paid to the fact that the perpendicular leg of the weld should always be to the left as shown at the top of Fig. 94.

The proper and improper use of the arrows to designate the member to be grooved is shown in Fig. 95.

Adequacy of symbolizing like adequacy of dimensioning must be governed by the particular conditions involved. In Fig. 96 are shown certain examples of inadequate symbolizing together with a suggested solution of the problem.

In Fig. 97 are shown proper and improper applications of the intermittent weld symbols.

A new feature incorporated in this revision is the use of the tail of the reference line for designating the welding specifications to be used in the making of the weld. If a welding operator knows the size and type of weld, he has only part of the information necessary for the making of that weld. The process, type and make of filler metal that is to be used, whether or not peening, or chipping are required and other pertinent data must be known before he can start the work. The specification to be placed in the tail of the reference line at present will have to be handled by each individual company which will set up its own requirement in any manner it sees fit, and it is hoped that in time a national set of standards will be prepared to coordinate the various specification processes in use. Steps in that direction are now under consideration. Such matters as stress-relief annealing, and final cleaning of the product cannot be referred to on the symbol because such treatment is applied to the product as a whole and not to a particular weld.

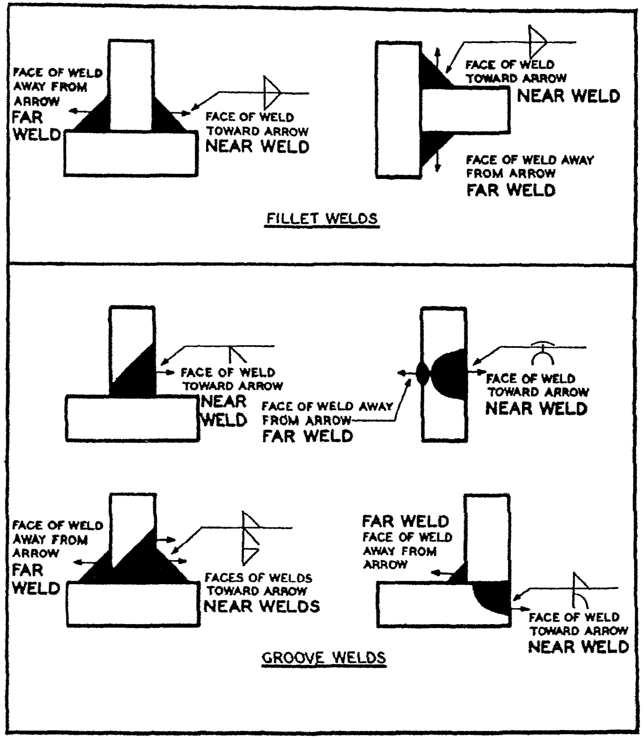


Fig. 92. Facing of welds shown in section and end views.

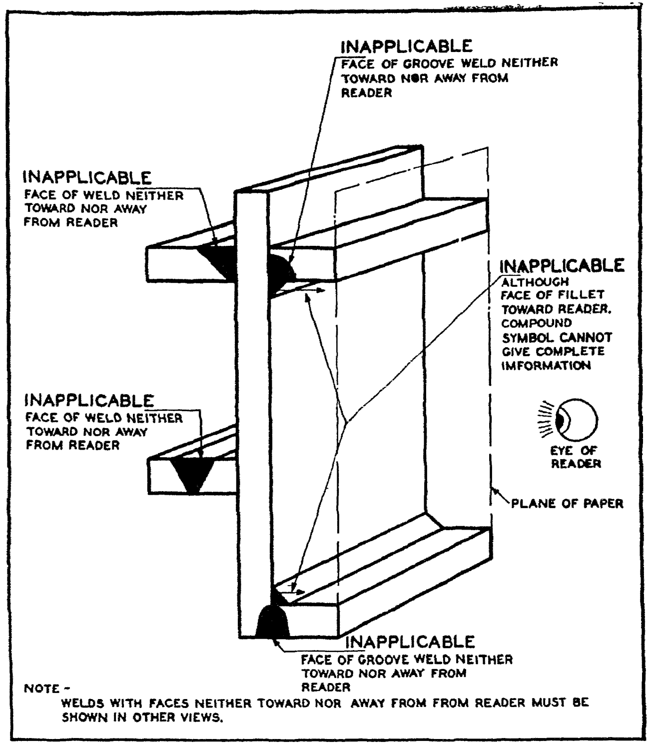


Fig. 93. Inapplicable facing of groove welds parallel to plane of paper.

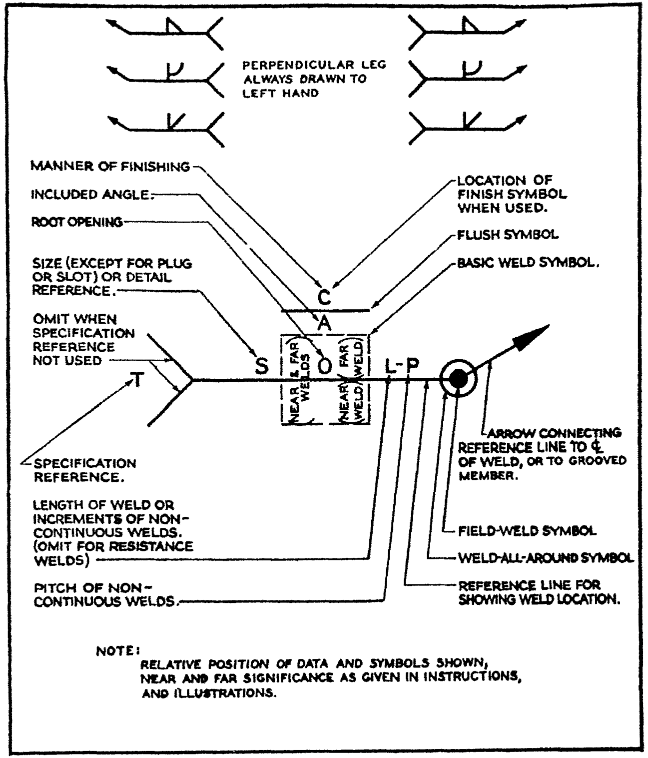


Fig. 94. Standard location of information on welding symbols.

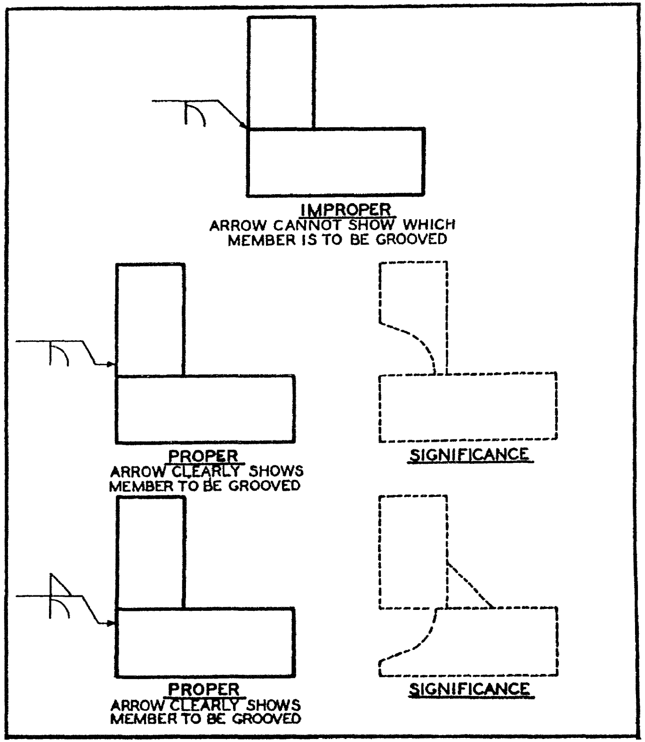


Fig. 95. Use of arrows in section or end view to indicate which member is to be grooved, when welds are not shown.

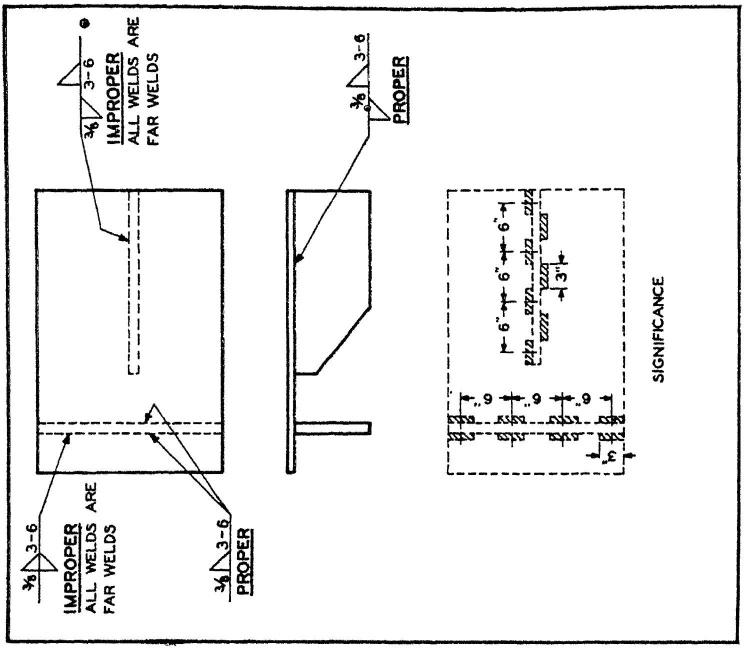


Fig. 97. Examples of use of intermittent weld symbols.

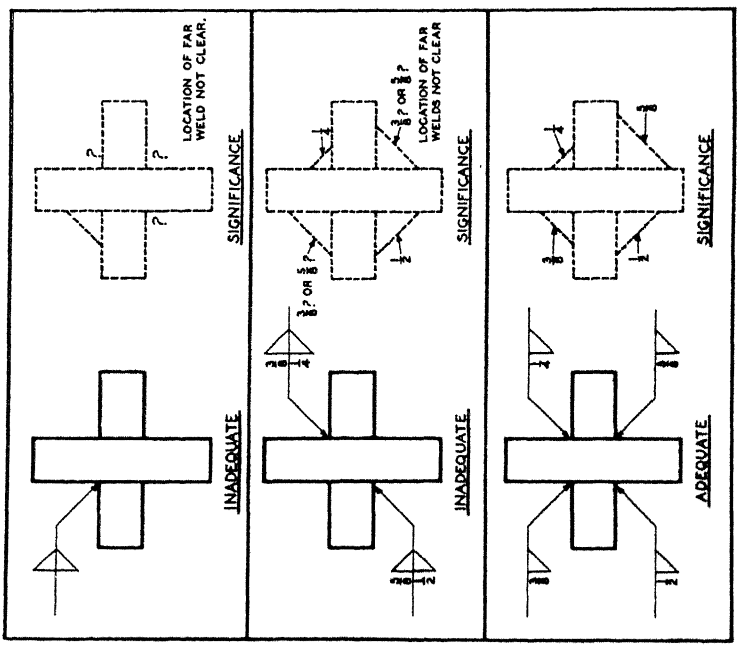


Fig. 96. Adequacy of symbolizing.

An example of a specification set up is shown in the table below.

Specification Number	Process	Filler Metal	Chipping of Root	Peening	Preheat	Specification Number
A1	Shielded Metal-Arc, Manual, D. C.	MILD STEEL (A.W.S. No. —)	None	None	None	A1
A2					Yes	A2
A3				Yes	None	A3
A4					Yes	A4
A5			Yes	None	None	A5
A6					Yes	A6
A7				Yes	None	A7
A8					Yes	A8
A9		HIGH TENSILE STEEL (A.W.S. No. —)	None	None	None	A9
A10					Yes	A10
A11				Yes	None	A11
A12					Yes	A12
A13			Yes	None	None	A13
A14					Yes	A14
A15				Yes	None	A15
A16					Yes	A16
A17		18-8 CORROSION RESISTING STEEL (A.W.S. No. —)	None	None	None	A17
A18				Yes	None	A18
A19			Yes	None	None	A19
A20				Yes	None	A20
A21		HARD SURFACING (A.W.S. No. —)	None	None	None	A21
A22					Yes	A22

SPECIFICATIONS FOR MAKING INDIVIDUAL WELDS

The symbols, together with the specification references, provide a shorthand system whereby a tremendous volume of information may be accurately indicated with a few lines and a minimum amount of numerical data. This is illustrated in Fig. 98, where the words necessary to convey the information given by the symbol would make a very long paragraph.

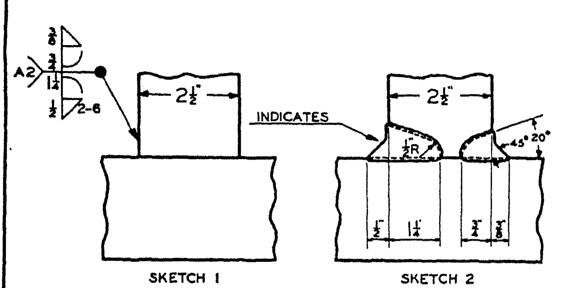
The use of the symbols on a machinery drawing is shown in Fig. 99, and on a structural drawing in Fig. 100. In these views examples of the use of the specification references are given.

In Fig. 101 are shown the resistance welding symbols. There are many similarities between the resistance and the arc welding symbols and three principal differences. The resistance symbols are only partially ideographic. The arc symbols designate the size of the weld, whereas the resistance welding symbols call for the strength of the required weld. This difference is necessary because in spot, projection and seam welding, the weld is inaccessible and therefore cannot be gaged as in fusion welding. Except for the case of projection welding where near and far refer to the member to be embossed, the resistance welding symbols have no near and far significance. Supplementary symbols such as those for "finish" have their usual near and far significance when used on resistance welding symbols.

The individual company may use just as much or as little of the system as it sees fit, and the system may be used in any of the various ways listed below:

(a) All symbol legends and explanatory matter may be issued as company standards on sheets separate from the drawing in question; that is, the draftsman may have explanatory supplementary sheets as well as machinists, welding operators, inspectors, etc. See remarks under "Introduction".

(b) Legends and specification references may be placed on the drawing so that the latter is completely self-explanatory.



INTERPRETATION OF SYMBOL:

DOUBLE-FILLET-WELDED, PARTIALLY-GROOVED, DOUBLE-J, TEE-JOINT WITH INCOMPLETE PENETRATION, (TYPE OF JOINT SHOWN BY DRAWING.) GROOVES OF STANDARD PROPORTIONS (WHICH ARE, 1/2"R, 20° INCLUDED ANGLE, EDGES IN CONTACT BEFORE WELDING) 3/4" DEEP FOR FAR WELD AND 1-1/4" DEEP FOR NEAR WELD. 3/8" CONTINUOUS FAR FILLET WELD AND 1/2" INTERMITTENT NEAR FILLET WELD WITH INCREMENTS 2" LONG, SPACED 6" CENTER-TO-CENTER. ALL FILLETS STANDARD 45° FILLETS. ALL WELDING DONE IN FIELD IN ACCORDANCE WITH WELDING SPECIFICATION NUMBER A2 (WHICH REQUIRES THAT WELD BE MADE BY MANUAL DC SHIELDED METAL-ARC PROCESS USING HIGH-GRADE, COVERED, MILD STEEL ELECTRODE; THAT ROOT BE UNCHIPPED AND WELDS UNPEENED BUT THAT JOINT BE PREHEATED BEFORE WELDING)

Fig. 98. Comparison between symbolic and verbal methods of conveying welding information.

(c) In either of the above cases, the welds may be drawn in sections and the symbol give only that information that is not obvious, such as size of weld, length of increment, etc.

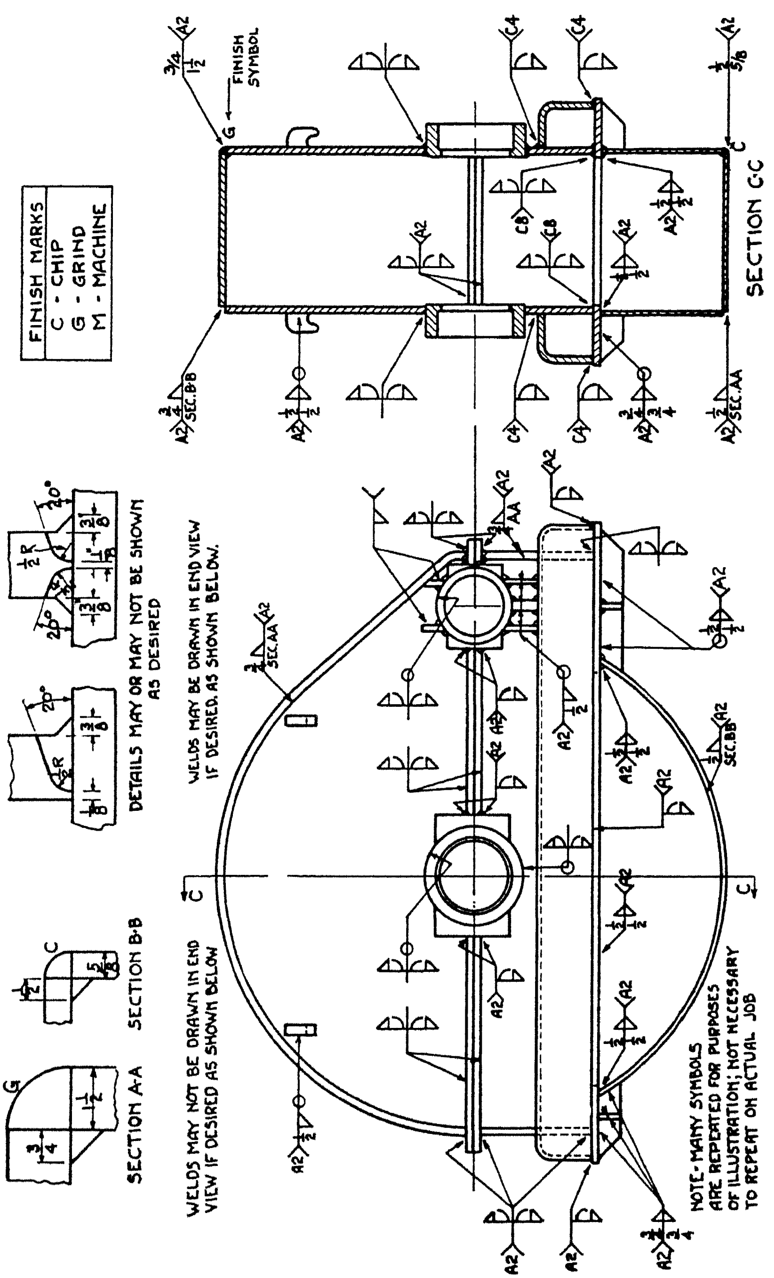


Fig. 99. Typical machinery drawing showing use of symbols.

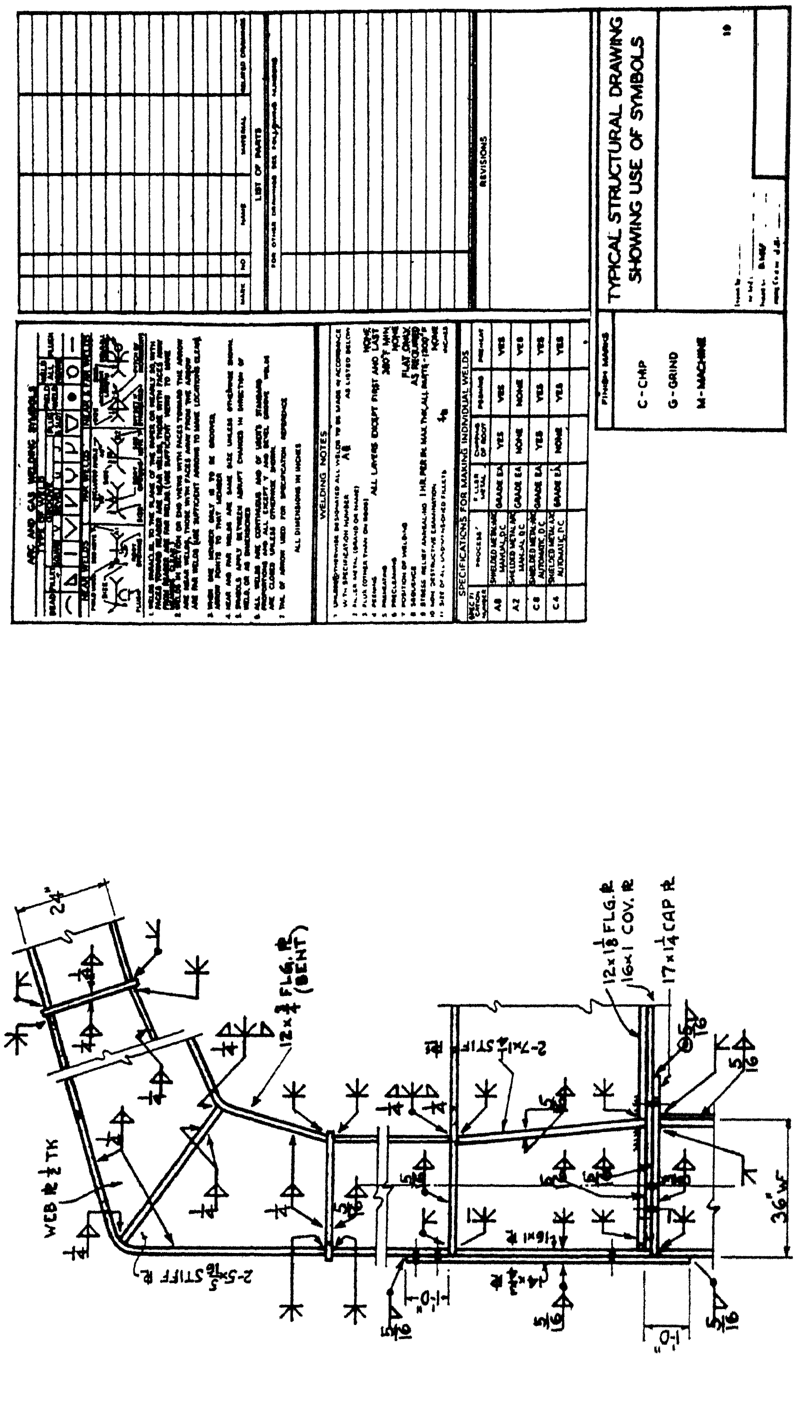
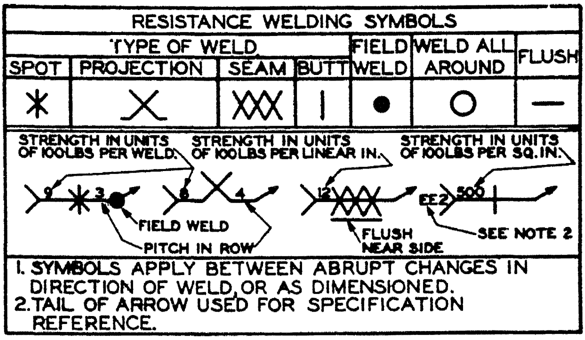


Fig. 100. Typical structural drawing showing use of symbols.

(d) In either of the cases (a) and (b) above, the welds may not be drawn in section and complete information conveyed by symbols.

(e) The symbol legends, specification references and standard notes may be printed on the tracing or may be placed on tracings or prints by rubber stamps or any other means.



ALL DIMENSIONS IN INCHES

Fig. 101. Legend for use on drawings specifying resistance welding.

INSTRUCTIONS FOR USE OF WELDING SYMBOLS

I General

(a) Do not use the word "weld" as a symbol on drawings.

(b) Symbols may or may not be made freehand as desired.

(c) Inch, degree, and pound marks may or may not be used as desired.

(d) The symbol may be used without specification references or tails to designate the most commonly used specification when the following note appears on the drawing:
"Unless otherwise designated, all welds to be made in accordance with welding specifications No. ...."

(e) When specification references are used, place in tail, thus:

(f) Symbols apply between abrupt changes in direction of weld or to extent of hatching or dimension lines.

(g) Faces of welds assumed to have user's standard contours unless otherwise indicated.

(h) Faces of welds assumed not to be finished other than cleaned unless otherwise indicated.

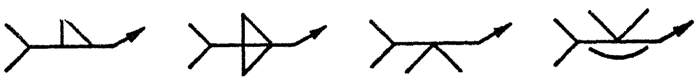
(i) All except plug, spot, and projection welds assumed continuous unless otherwise indicated.

(j) All exxcept V- and bevel-grooved welds are assumed to be closed unless otherwise indicated.

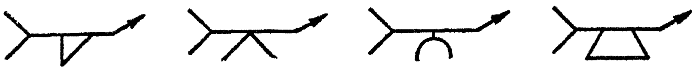
II Metal-Arc Welds

1. General

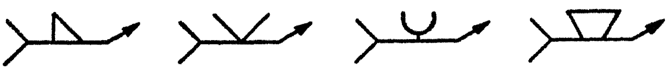
(a) Do not put symbol directly on lines of drawing; place symbol on reference line and connect latter to joint with arrow, thus:



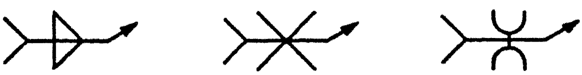
(b) For near welds show symbol on near side of reference lines, face toward reader, thus:



(c) For far welds show symbol on far side of reference line, face away from reader, thus:



(d) For both near and far welds show symbols on both sides of reference line, faces toward and away from reader, thus:



(e) For welds parallel to the plane of the paper or nearly so, near and far refer to the nearest welds or groups of welds and not to others on members or parts of members more remote.

(f) Show near welds in section and end views by pointing the arrow in such a way that the face of the weld is or will be toward the arrow; see Fig. 92.

(g) Show far welds in section and end views by pointing the arrow in such a way that the face of the weld is or will be away from the arrow; see Fig. 92.

(h) If the face of a weld parallel or nearly so to the plane of the paper is or will be neither toward nor away from the reader, the symbols are not applicable; see Fig. 93. The weld should be shown in another view.

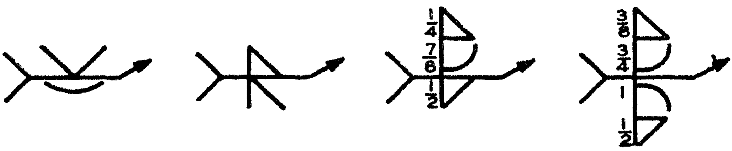
(i) If one of the welds of a compound weld parallel or nearly so to the plane of the paper is or will be located in such a way that the face of that weld is neither toward nor away from the reader, a compound symbol should not be used, even though other unit welds in that group may face either toward or from the reader; see Fig. 93. The compound weld should be shown in another view.

(j) Where several welds are involved in one group and there is a possibility of ambiguity, use sufficient number of symbols to adequately convey the desired information; see Fig. 96.

(k) Where one member only is to be grooved, show arrow pointing to that member with the arrow practically perpendicular to the face of the desired weld; see Fig. 95.

(l) Read symbols from bottom and right-hand side of drawing in the usual manner and place numerical data on vertical reference lines so that reader will be properly oriented, thus:

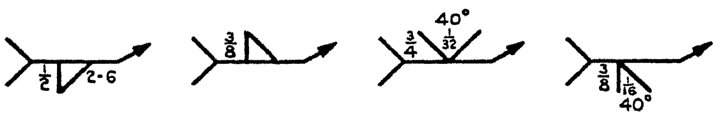
(m) Show symbol for each weld in joints composed of more than one weld, thus:



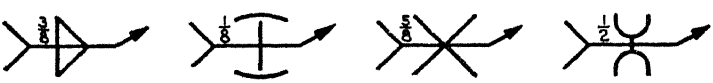
(Give numerical data in proper location with regard to each symbol.)

(n) In complicated joints requiring large compound symbols two separate sets of symbols may be used if desired.

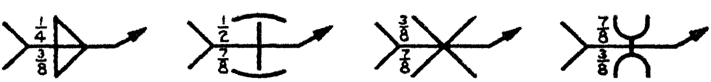
(o) Show dimensions of weld on same side of reference line as symbol, thus:



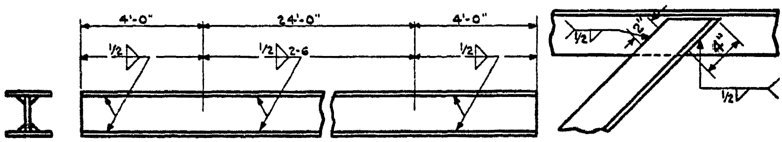
(p) Show dimensions of one weld only, when near and far welds are of the same size, thus: (If size of undimensioned fillets is governed by note on drawing, all weld sizes different from that covered in the note must be given.)



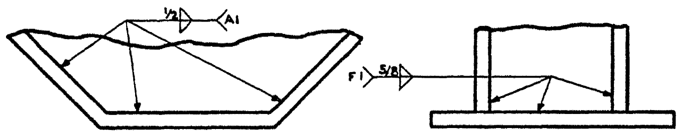
(q) Show dimensions for both welds when near and far welds are different, thus:



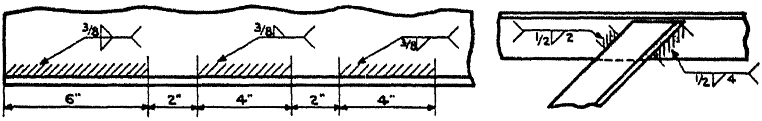
(r) Indicate specific lengths of welds in conjunction with dimension lines, thus:



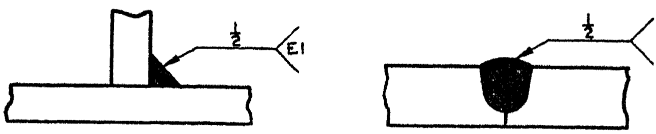
(s) Show the welding between abrupt changes in direction of the weld, thus:



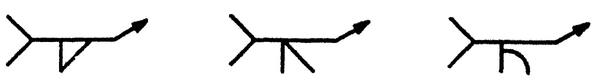
(t) When it is desired to show extent of welds by hatching, use one type of hatching with definite end lines, thus:



(u) If actual outlines of welds are drawn in section or end elevation, basic symbol is not necessary to show type and location; size or other numerical details only need to be given, thus:



(v) Show fillet, bevel and J-groove weld symbols with perpendicular leg always to the left hand, thus:



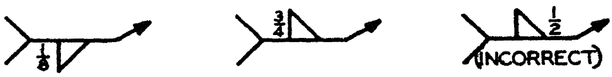
2. Bead Welds

(a) Show bead welds used in building up surfaces (size is minimum height of pad) thus:

(b) When a small but no specific minimum height of pad is desired, show thus:

3. Fillet Welds

(a) Show size of fillet weld to the left of the perpendicular leg, thus:

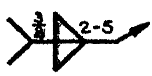


(b) Show specific length of fillet weld or increment after size so that data reads from left to right, thus:

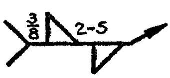
(c) Show center-to-center pitch of increments of intermittent fillet welds after increment length so that data reads from left to right, thus:

(d) Use separate symbol for each weld when intermittent and continuous fillet welds are used in combination.

(e) Show two intermittent fillet welds with increments opposite each other (chain) thus:

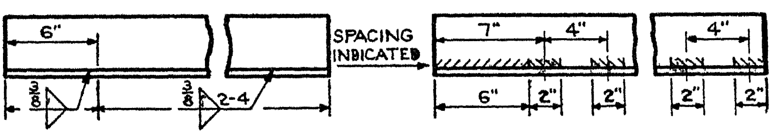


(f) Show two intermittent fillet welds with increments not opposite each other (staggered) thus:



(g) Measure pitch of intermittent fillet welds between centers of increments on one side of member.

(h) Increments and not spaces assumed to be at ends of all intermittent welds and overall length dimensions govern to ends of those increments, thus:

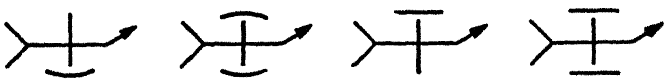


(i) Faces of fillet welds assumed to be at 45° from legs unless otherwise indicated.

(j) When the face of a fillet weld is to be at any other angle then 45°, two dimensions are necessary to fully designate the size of the weld. Place these dimensions in parentheses so that the two dimensional size data will be a single entity and will not be confused with length of increment and spacing data. Show on drawings positions of legs relative to members.

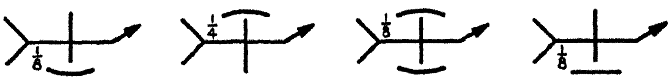
4. Grooved Welds

(a) Show side from which square-grooved weld is made by bead or flush symbol, thus: (see III, 4a; IV, c; and IV, e)

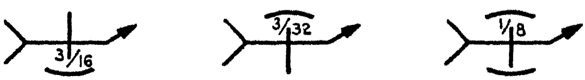


(b) Total penetration of square-grooved welds assumed to be complete unless otherwise indicated.

(c) Show size of square-grooved welds (depth of penetration) when penetration is less than complete, thus:

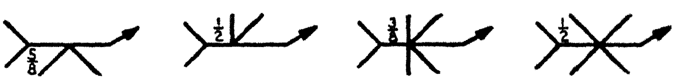


(d) Show root opening of open, square-grooved welds inside symbol, thus:



(e) Total depth of V- and bevel-grooves before welding assumed to be equal to thickness of member unless otherwise indicated.

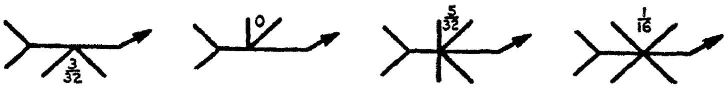
(f) Show size of V- and bevel-grooved welds (depth of single groove before welding) when grooving is less than complete, thus:



(g) Total depth of penetration of V- and bevel-grooved welds assumed complete, unless with usual welding processes, depth of grooving is such that complete penetration is not possible, when depth of penetration is assumed to be depth of groove plus normal penetration. When using welding processes giving abnormal penetration, give information on latter by detail or note, (see IV, j).

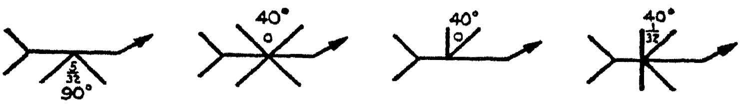
(h) Root opening of V- and bevel-grooved welds assumed to be user's standard unless otherwise indicated.

(i) Show root openings of V- and bevel-grooved welds when not user's standard, inside symbol, thus:



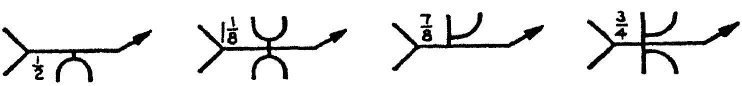
(j) Included angle of V- and bevel-grooved welds assumed to be user's standard unless otherwise indicated.

(k) Show included angle of V- and bevel-grooved welds when not user's standard inside symbol, thus:

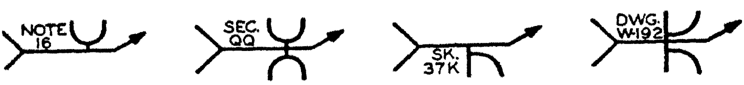


(l) Proportions of U- and J-grooved welds assumed to be user's standard unless otherwise indicated.

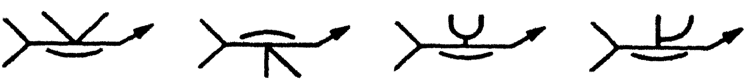
(m) Show size of U- and J-grooved welds (depth of single groove before welding) having user's standard proportions but incomplete penetration, thus:



(n) When proportions of U- and J-grooved welds are not user's standard, show weld by detail or reference drawing and use reference symbol, thus (see IV, j):



(o) Show welding done from root side of single grooved welds with bead weld symbol, thus:



5. Plug and Slot Welds
   (a) Show size of plug and slot welds (root opening and root length), thus:

   (Root opening equals root length for plug welds.)

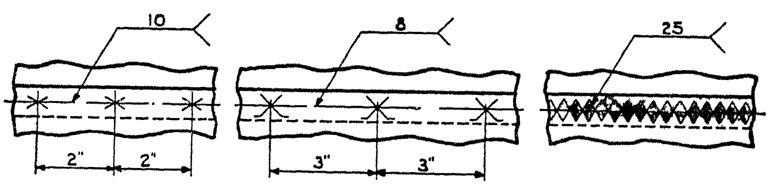
   (b) Included angle of bevel of plug and slot welds assumed to be user's standard unless otherwise indicated.
   (c) Show included angle of bevel of plug and slot welds when not user's standard, thus:

   (d) Show pitch of plug and slot welds in row, thus:

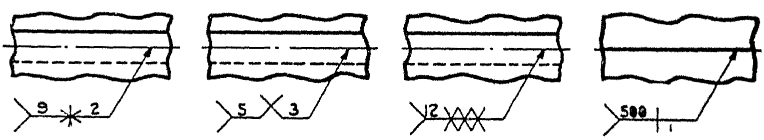
   (e) Show fillet welded holes and slots with proper fillet weld symbols and not with plug weld symbols.

III RESISTANCE WELDS

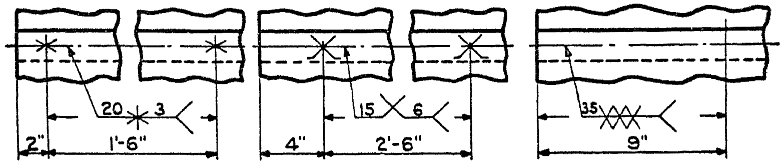
1. General
   (a) Center resistance welding symbols for spot and seam welds on reference line because these symbols have no near and far significance; see Fig. 101, (also refer to IV, h) but do not center projection welding symbol because the latter has such significance.
   (b) Designate resistance welds by strength rather than size (because of impracticability of determining latter).
   (c) Spot and seam weld symbols may be used directly on drawings, thus; but projection weld symbols should not.



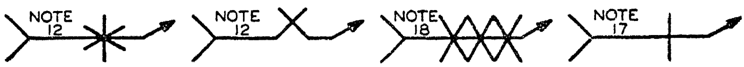
   (d) When not used on lines of drawing, connect reference line to center line of weld or rows of welds with arrow, thus:



(e) Show welds of extent less than between abrupt changes in direction of joint, thus:



(f) When tension, impact, fatigue or other properties are required, use reference symbol, thus: (see IV, j)



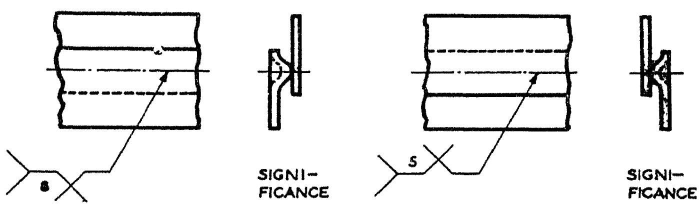
2. Spot and Projection Welds.

(a) Show strength of spot and projection welds in single shear in units of 100 pounds per weld, thus:

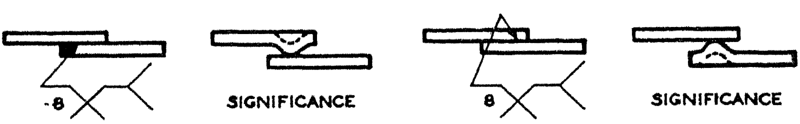
(b) Show strength and center-to-center spacing of spot and projection welds in row, thus:

(c) Proportions of projections assumed given on drawing.

(d) In a projection welded joint parallel or nearly so to the plane of the paper, show whether the near or far member is to be embossed by placing the projection weld symbol on the near or far side of the reference line, thus:



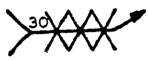
(e) In a projection welded joint shown in section or end view, show which member is to be embossed by pointing arrow to that member, thus:



3. Seam Welds

(a) Seam welds assumed to be of overlapping or tangent spots. If any spacing exists between spots, welds considered a series of spot welds, and spot symbol should be used.

(b) Show shear strength of seam welds in units of 100 pounds per linear inch, thus:

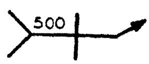


4. Butt Welds

(a) Show resistance butt welds without bead weld symbol signifying that weld is not made from any side, but all at once, thus: (See II, 4a)

(b) Resistance butt welds assumed to be equal to strength of base metal in tension unless otherwise indicated.

(c) When a different strength is desired, show strength of butt welds in tension in units of 100 pounds per square inch, thus:



IV SUPPLEMENTARY SYMBOLS

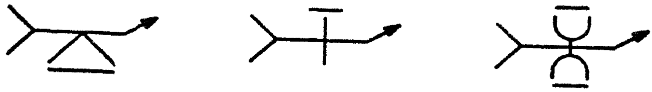
(a) Show "field" welds (any weld not made in shop), thus:

(b) Show "all around" welds (weld encircling member insofar as possible), thus:

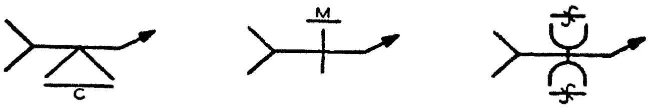
(c) The location of the flush and finish symbols have the usual near and far significance and govern only the sides on which they are shown.

(d) Finish marks govern faces of welds only and not base metal either before or after welding.

(e) Show arc and gas welds made flush without recourse to any kind of finishing, thus:



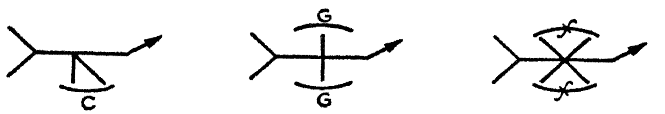
(f) Show arc and gas welds made flush by mechanical means with both flush and user's standard finish symbols, thus:



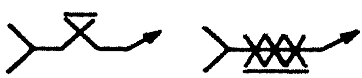
The following letters are suggested for indicating finishing processes:

C — Chip G — Grind M — Machine

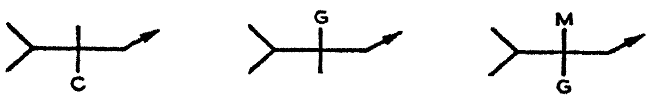
(g) Show finishing on face of arc and gas welds, which need not be flush, with user's standard finish symbols on bead symbol, thus:



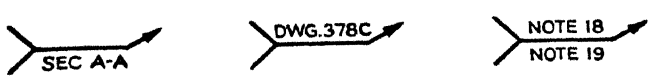
(h) Show spot, seam, or projection welds made practically flush (with minimum indentation), thus:



(i) Show resistance butt welds, finished by mechanical means, without flush symbol, thus:



(j) Show special welds not covered by any of the above symbols by a detailed section or reference drawing, or give any supplementary information by means of a note and refer weld to section, drawing, or note by a reference symbol. Reference symbol has usual location significance, **thus:**



Strength of Welded Joints.—Calculation of the designed strength of any welded joint should include consideration of the following factors:

(1) Strength of weld metal.
(2) Type of weld.
(3) Location of weld in relation to parts joined.

In calculating the strength of fillet welds, a unit stress of 13,600 lbs. per square inch is usually employed for tension, shear and compression since in practically every fillet weld shear is present.

SAFE ALLOWABLE LOADS FOR FILLET WELDS IN SHEAR

Size of Fillet Weld	Pounds per Lineal Inch — "Fusion Code" (Structural) — A.W.S.
1/8"	1200
3/16"	1800
1/4"	2400
5/16"	3000
3/8"	3600
1/2"	4800
5/8"	6000
3/4"	7200

For dynamic, vibrational or lifting loads, the unit stress of fillet welds, or the strength per lineal inch, should be reduced, depending upon the severity of the load.

Approximately 1/4" should be added to the designed length of fillet welds for starting and stopping the arc. The crater in the welds should be filled.

In the table, Page 67, is given the proper lengths of various sizes of fillet welds having shear values equivalent of various sizes of rivets.

The working strength of *butt welds,* of 100% penetration into the base metal, is usually calculated by multiplying the net cross sectional

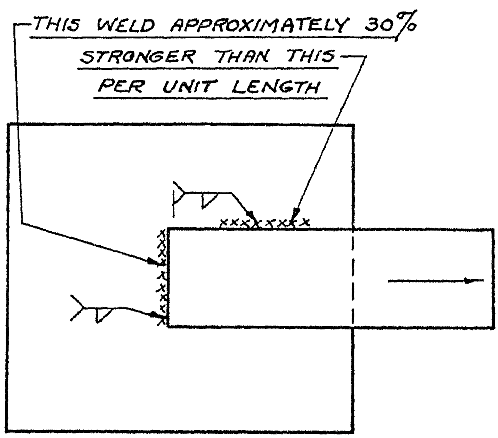


Fig. 102. Transverse welds are stronger than welds parallel to lines of stress.

area through the throat of the weld by 15,600 lbs., for tension — by 13,600 lbs. for shear — by 18,000 lbs. for compression.

The *location of the welds* in relation to the parts joined, in many cases, *has an effect on the strength of the welded joint.* As an example, repeated tests reveal that, when other factors are equal, welds having their linear dimension transverse to the lines of stress are approximately 30% stronger per average unit length than welds with linear dimension parallel to lines of stress. This is depicted graphically in Fig. 102, and is due to the stress distribution along the bead.

LENGTH OF FILLET WELD TO REPLACE RIVETS

Rivet Dia. Size	Rivet Shear Value @ 12,000 lbs. per sq. in.	Length of Fillet Welds (to nearest 1/8") — "Fusion Code" (Structural) Shielded Arc Welding				
		1/4" Fillet	5/16" Fillet	3/8" Fillet	1/2" Fillet	5/8" Fillet
1/2"	2356	1 1/4"	1 "	15/16"	3/4"	11/16"
5/8"	3682	1 3/4"	1 1/2"	1 1/4"	1 "	7/8"
3/4"	5301	2 1/2"	2 "	1 3/4"	1 3/8"	1 1/8"
7/8"	7216	3 1/4"	2 1/4"	2 1/4"	1 3/4"	1 1/2"
1"	9425	4 1/4"	3/8"	3 "	2 1/4"	1 7/8"

Note: 1/4" is added to calculated length of fillet.

If the load on the weld is to be properly distributed the welds should be located so as to take account of the shape of the sections joined. An example is illustrated by Fig. 103. The ratio of the lengths of the welds at heel and toe of the angle is such that there will be no tendency for the angle to turn and thus cause eccentric loads on the joint.

Resistance to a turning effect of one member at a joint is best obtained by welds well separated rather than by a single weld or welds close

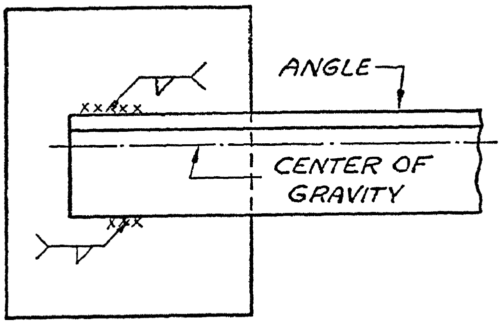


Fig. 103. Example of correct lengths of welds for equal load distribution.

together. In Fig. 104 a single weld at *A* is not as effective as welds at both *A* and *B* in resistance to turning effect. Two small welds at *A* and *B* are much more effective than a large single weld at *A* or *B* only.

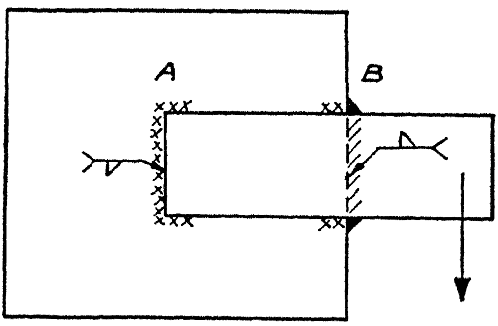


Fig. 104. Example of proper placement of welds to resist turning effect of one member at the joint.

If possible, welded joints should be designed so that bending or prying action is minimized. Symmetrical joints are most desirable as they are very much stronger than non-symmetrical joints, the stress in symmetrical joints being more evenly distributed.

In some designs it may be desirable to take into account the distribution of stress through the welds in a joint. It is known that any abrupt change in surface (for example, a notch or saw cut in a square bar under tension) increases the local stress or causes stress concentration. As an

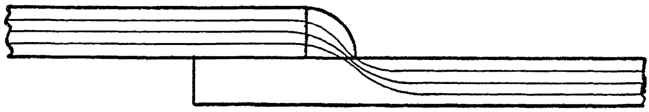


Fig. 105. Example of lap weld having poor distribution of stress through weld.

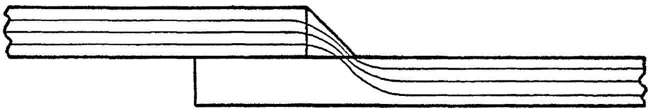


Fig. 106. Example of lap weld having a more even distribution of stress through weld.

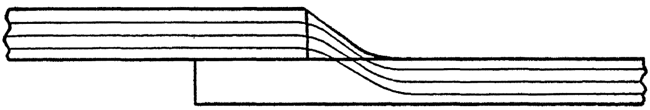


Fig. 107. Example of lap weld in which there is a fairly uniform transfer of stress through the weld.

illustration of this principle, the weld, Fig. 105, will have considerably more concentration of stress than that in Fig. 106. Figure 107 allows a much more uniform transfer of stress with a resulting minimum of stress concentration. In many cases such concentration of stress might be small and of minor consequence. However, in heavy or repeated loadings this matter should have the attention of the designer.

Stress in a weld having its linear dimension approximately parallel to the line of force is not evenly distributed. Under many load conditions, not at all unusual, the stress is greater at the ends of the weld than in the middle. It is therefore advisable in certain conditions to hook the bead around the joint as indicated in Fig. 108. When this is done, far greater resistance to a tearing action on the weld is obtained.

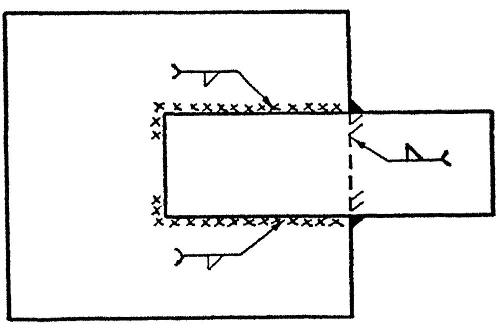


Fig. 108. Example of welds hooked around the corners to obtain resistance to tearing action on welds when subjected to eccentric loads.

These allowable loads are based on a stress of 13,600 lbs./sq. in. in throat section as specified in Structural Code of A. W. S. They are conservative, being based on a factor of safety of about 5, since weld metal has 60,000 to 65,000 lbs./sq. in. ultimate strength.

In many cases it may be exceeded by 20% or more, depending upon the type of load and character of joint. Then, it would still give factor of safety of about 4.

Stress Calculations—In only a few cases is the stress uniformly distributed. However, in designing it is customary to make the assumption that stress distribution is uniform in all cases. Any condition which seriously interferes with this assumption must be given thoughtful consideration. On this basis the following methods may be used:

The following methods may be used as guides in estimating weld dimensions to meet designed strength requirements.

Assume a plate to which a bar or strap is welded, as in Fig. 109. Direct tension, no bending or eccentric loading resulting in shear on the beads. The load is known and dimensions of the plate are known.

If P = load
S = stress in lbs. per sq. in. in plate
t = thickness of plate
and b = width of plate
then P = S x t x b

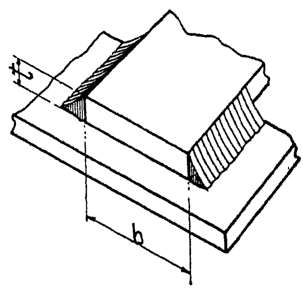


Fig. 109.

The structural code permits 13600 lbs. per sq. in., in shear on throat area. The load value of a 1-inch fillet weld in longitudinal shear is 9600 lbs. per lineal inch with shielded arc type electrodes (.707 x 13600 = 9600). With other types of electrodes, load values will be lower.

Two beads of equal length and size equal to plate thickness are used in Fig. 109; consequently the total bead capacity is 2 x t x 9600 lbs. per lineal inch. Since load equals S x t x b, the effective length of weld per side will be

$$L = \frac{S \times t \times b}{2 \times t \times 9600} = \frac{S \times b}{2 \times 9600}$$

As an example, assume that S equals 16,000 lbs. per sq. in. unit stress.

$$\text{Then, } L = \frac{16{,}000 \times b}{2 \times 9600} = .833\ b$$

If unit stress in the plate is expressed in Kips (1000 lbs.) per sq. in., multiply this by plate width (inches) and divide by 19.2 to obtain effective length of bead per side, e. g.:

$$\frac{b \times K}{19.2}$$

Where
K = Kips

The following tabulation, which may be extended, is an example:

$$L = \frac{b \times K}{19.2} \quad \text{Effective length of bead each side}$$

Plate Width (b) Inches	VALUES OF "L"						
	Unit Stress in Plate-Kips (K)						
	8	10	12	14	16	18	20
1	.42	.52	.625	.73	.83	.94	1.04
2	.84	1.04	1.250	1.46	1.66	1.88	2.08
3	1.26	1.56	1.875	2.19	2.49	2.82	3.12
4	1.68	2.08	2.5	2.92	3.32	3.76	4.16
5	2.1	2.6	3.125	3.65	4.15	4.7	5.20
6	2.52	3.12	3.75	4.38	4.98	5.64	6.24

The same method can be used for estimating effective lengths of beads for joining angles to plate as in Fig. 110. where the legs of the angle are equal.

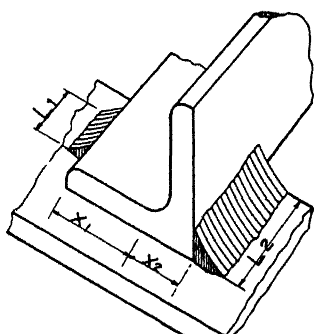


Fig. 110.

If t equals thickness and a equals length of leg, then the area is approximately:

$$\begin{aligned} A &= t\,(a + a - t) \\ &= t\,(2a - t) \\ &= 2ta - t_2 \end{aligned}$$

Since the t^2 may be dropped and still retain an ample margin of safety, the area becomes 2 ta. Load is, therefore, 2ta x S. Assuming bead capacity as t x 9600 and calculating bead length as outlined for Fig. 109, we have:

$$\frac{2ta \times S}{t \times 9600} = \frac{2aS}{9600} = \text{total bead length}$$

In angle connections of the type shown in Fig. 110, it is customary to proportion the beads inversely as their distance from the center of gravity. Therefore, in proportioning the two beads, the shorter bead (at toe of angle) will be ⅓ of the total bead length since the distance from the center of gravity to the heel of the angle is ⅓a. The shorter bead will then be

$$\frac{1}{3} \times \frac{2aS}{9600} = \frac{9S}{14400} = \frac{aK}{14.4}$$

As an example, again assume that S equals 16,000 lbs. per sq. in. unit stress. Then shorter bead will be

$$\frac{1 \times a \times 16}{14.4} = 1.11a \ (a \text{ being length of leg})$$

This is for unit stress of 16,000 lbs. per sq. in. in angle. Using the more general expression for length of the short bead, we should have:

$$\frac{2a}{3} \times \frac{K}{9600} = \frac{aK}{14.4}$$

The short bead of a 3-inch angle with 18,000 lbs. per sq. in. unit stress, welded as in Fig. 110, would be:

$$3 \times \frac{18}{14.4} = 3.75 \text{ inches}$$

The longer bead would, of course, be twice the shorter or 7.5 inches.

Expressed as a general statement, multiply unit stress in angle in Kips by length of leg and divide by 14.4 to obtain length of shorter bead.

$$\frac{a \times K}{14.4}$$ The longer bead is twice this value.

A few examples will illustrate how tabulations of bead lengths for angles may be quickly made.

Length of Bead (Shorter). Equal Leg Angles.

Angle	Length of Bead — Inches						
	Unit Stress in Angle-Kips						
	8	10	12	14	16	18	20
2 x 2	1.11	1.39	1.67	1 94	2.22	2.5	2.78
3 x 3	1.67	2.08	2 5	2.93	3.33	3.75	4.17
4 x 4	2 22	2.78	3.34	3 38	4.44	5.0	5.56

Longer bead = two times length of shorter bead.

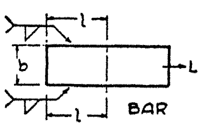
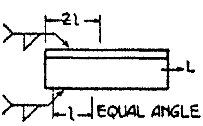
Obviously a less approximate method would be to use the dimensions of the angle as given by the steel manufacturers. On the basis of unit stress in angle of 20,000 lbs. per sq. in. — which figure is used because of the ease with which values at other stresses may be obtained—e. g., at 18,000 lbs. per sq. in.—

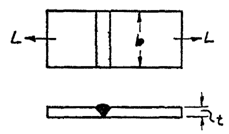
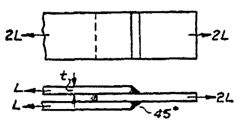
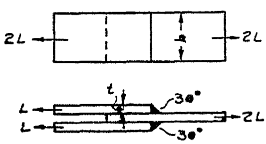
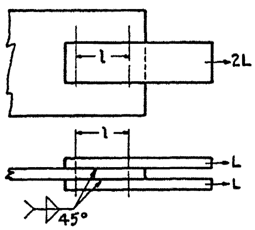
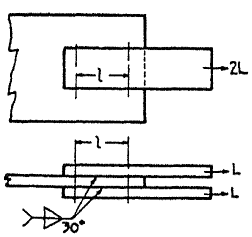
$$\text{bead length} = \frac{18000}{20000} \text{ or .9 length as given in table.}$$

The following illustrative tabulations are given:

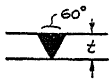
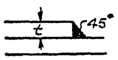
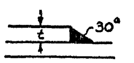
Size of Angle	Area Sq. In.	Distances Bead to Center of Gravity		Load (Kips) Area x 20 Kips	Length Beads	
		X_1	X_2		*$L_1 = \frac{\text{Load x } X_2}{\text{a x 9.6 x t}}$	$L_2 = \frac{\text{Load x } X_1}{\text{a x 9.6 x t}}$
2 x 2 x ¼	.94	1.41	.59	18.8	2.31	5 52
2 x 2 x ⅜	1.36	1.36	.64	27.2	2.45	5.13
2½ x 2½ x ¼	1.19	1.78	.72	23.8	2.85	7.07
3 x 3 x ¼	1.44	2.16	.84	28.8	3.37	8.65
3 x 3 x ⅜	2.11	2.11	.89	42.2	3.48	8.25
4 x 4 x ¼	1.94	2.91	1.09	38.8	4.4	11.8
4 x 4 x ⅜	2.86	2.86	1.14	57.2	4.55	11.3
4 x 4 x ½	3.75	2.82	1.18	75.	4.6	11.0

*It is usual to make this bead somewhat smaller in size than "t" and therefore longer than indicated above, because of shape of angle edge.

Type of Joint	Throat Area One Bead	Unit Stress Lbs./Sq. In.	Size of Bead
	.707 t l	K = Unit Stress in Kips in bar $= \frac{L}{t\,b\,(1000)}$	$= \frac{b\,K}{20}$ l = Effective length one bead
	.707 t l	K = Unit Stress in Kips a = length of leg	$l = \frac{a\,K}{15}$

Type of Joint	Throat Area One Bead	Unit Stress in Throat Area Lbs. per Sq. In. (S)	Size of Bead (t)
	t b	$\frac{L}{t\,b}$	$\frac{L}{S\,b}$
	$\frac{\sqrt{2}\,t\,b}{2}$ 707 t b	$\frac{\sqrt{2}\,L}{t\,b}$ $\frac{1.414\,L}{t\,b}$	$\frac{\sqrt{2}\,L}{S\,b}$ $\frac{1.414\,L}{S\,b}$
	$\frac{\sqrt{3}\,t\,b}{2}$ .865 t b	$\frac{2\,L}{\sqrt{3}\,t\,b}$ $\frac{1.153\,L}{t\,b}$	$\frac{2\,L}{\sqrt{3}\,S\,b}$ $\frac{1.153\,L}{S\,b}$
	$\frac{\sqrt{2}\,t\,l}{2}$ .707 t l	$\frac{2\,L}{2\sqrt{2}\,t\,l}$ $\frac{.707\,L}{t\,l}$	$\frac{2\,L}{2\sqrt{2}\,S\,l}$ $\frac{.707\,L}{S\,l}$
	$\frac{\sqrt{3}\,t\,l}{2}$ .865 t l	$\frac{2\,L}{2\sqrt{3}\,t\,l}$ $\frac{.576\,L}{t\,l}$	$\frac{2\,L}{2\sqrt{3}\,S\,l}$ $\frac{.576\,L}{S\,l}$

Other interesting data may be worked out on the same basis, i.e., uniform stress distribution. Assume a plate of breadth b and thickness t transmitting a load. Then for the same unit stress in the plate the following is true.

Type of Joint	Volume of Bead	Unit Stress in Bead	Ratio of Unit Stresses in Bead	Volume for Same Unit Stress in Bead	Ratio of Volumes for Same Stress
	$\frac{t^2 b}{\sqrt{3}}$	$\frac{L}{t b}$	1	$\frac{t^2 b}{\sqrt{3}}$	1
	$\frac{t^2 b}{2}$	$\frac{\sqrt{2} L}{t b}$	$\sqrt{2}$ or 1.414	$t^2 b$	1.73 or $\sqrt{3}$
	$\frac{\sqrt{3} t^2 b}{2}$	$\frac{2 L}{\sqrt{3} t b}$	$\frac{2\sqrt{3}}{3}$ or 1.1153	$\frac{2\sqrt{3} t^2 b}{3}$	2

STUDY OF STRESS DISTRIBUTION IN WELDED JOINTS

By means of rubber models—If, in one part of a structure, the stress is high as compared to another part it is obvious that the high stress will be the governing factor in determining the load capacity of that member. If, however, the stress is uniformly distributed, more load can be carried or a smaller section can be used for a given load with a resultant cost reduction. See Page 210. The problem of stress distribution caused by a given load should therefore be approached not from that of eliminating high stress at one particular point to meet specific load condition at that point, but to meet all load conditions at all points with a maximum efficiency. Even though the maximum stress is rather low, if the uniformity of its distribution is improved the cost is reduced. By proper study, it is possible to obtain highly uniform stress distribution.

A simple, inexpensive and effective method of studying stress distribution is by means of two-dimensional rubber models. Rubber of uniform thickness, ruled in squares is generally used. On the rubber is laid out the type of joint to be studied. The joint is cut out so that in effect the result is a two-dimensional joint in rubber. See Fig. 111. The joint is then subjected to loads (generally tension) and the deformations are studied. The method of studying is as follows:

After the particular joint to be studied has been cut out of rubber, the dimensions of the squares are measured at various points. By pulling the sample and observing the change in dimensions it will be evident where the points of maximum deformation occur and squares will be measured at these points, at points where minimum deformation occurs and at the points where the stress is distributed uniformly. The load is then removed and the squares measured at these points.

The load is changed and the dimensions of the squares are measured again at these same points. In like manner, several loads of various amounts are applied and measurements are made for each load. The dimensions of the squares under load are of course, greater than under no load. The difference between the load dimensions and the no-load dimensions give an indication of the stress value at that particular point because they indicate the distortion at that point.

The ratio of the deformation at a point stressed above the average to the deformation at a point of uniform stress is the ratio of stress distribution.

Knowing this stress ratio and the value of the actual stress at the point of uniformity obtained from the design calculation, this higher stress is obtained by multiplying this uniform stress by the stress ratio. If this ratio is too high and a more uniform distribution is sought then modifications of the joint must be made and the operation repeated. After a reasonable amount of practice in the use of this method, the modification necessary to produce a uniform stress distribution will become apparent.

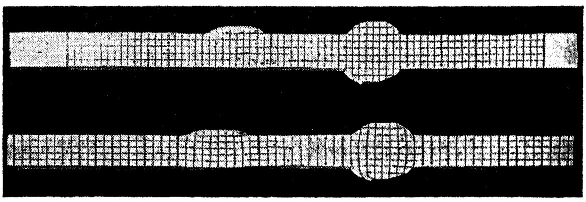


Fig. 111 (above). Fig. 112 (below).

It is sometimes convenient to place two joints on the same specimen so that they may be compared directly while subjected to the same load. Such a method is used in comparing a standard type of joint to a proposed non-standard joint or a joint of characteristics which may not be particularly satisfactory. For example, note in Fig. 111 and Fig. 112 the extremely heavy reinforcement on the right as compared to a normal amount of reinforcement on the left.

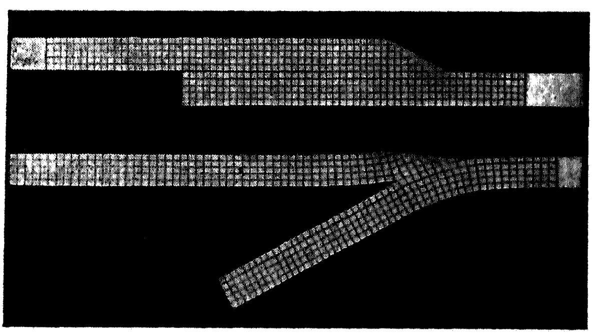


Fig. 113 (above). Fig. 114 (below).

At the outer edges of the reinforcement the stress is very low while in the center of the joint it is higher, indicating an uneven stress distribution and a poor use of material and a relatively high cost. Reduction of the reinforcement results in improvement of the quality of the joint and a cost reduction. It is evident that the stresses are not particularly high but that the use of the material is not particularly good.

A single-bead lap joint shown in Fig. 113 and Fig. 114 is compared to a riveted joint shown in Fig. 115 and Fig. 116. Note the non-uniformity of stress distribution in the riveted joint and the relative excess of material.

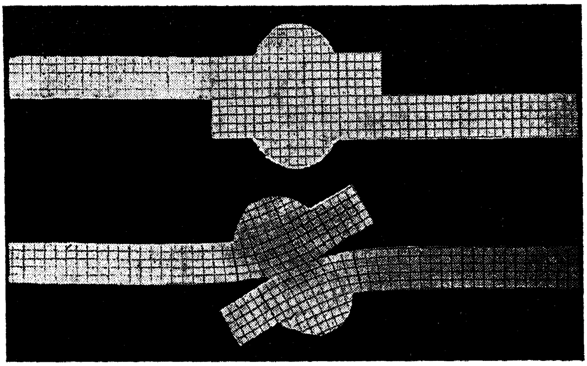


Fig. 115 (above). Fig. 116 (below).

On the riveted joint shown in Figs. 115 and 116 the plate and rivet are integral which is not the case with an actual riveted joint. Moreover, it should be noted that in these samples, no clamping action exists as would be the case in steel riveted joints due to the contraction of the rivet.

A study of these joints as exemplified in the two simple examples shown, indicates that the stress conditions existing in a joint may be studied readily, permitting the designer a method of obtaining a more uniform stress distribution and therefore better performance and lower cost. Because of the ease with which welding can be used in fabrication of parts and the control of the shape of those parts by welding, adjustment in the shape of these parts can be made so that every part is utilized to the best possible advantage.

Study of Stress Distribution by Means of Celluloid Models.—A method of study of stress distribution has been outlined under previous paragraphs and it would be well to read again the remarks made therein as to the desirability of obtaining uniform stress distribution and the effect this has on the reduction of costs.

Another method of study of stress distribution is that based on the study of a stressed model of a suitable material, such as celluloid. This model is placed in a beam of polarized light and the resultant effect upon the polarized beam is studied, affording a simple, quick and reliable method of studying stress relationship. It is not necessary

to go into any elaborate mathematical calculations (numerous text books cover this subject).

The method consists of passing a beam of polarized light through some isotropic transparent substance, such as celluloid. When this material, such as celluloid, is stressed, there is an effect upon this beam of polarized light which is indicated by colors, different bands of colors, and different arrangements of these bands. If a model is made of a joint to be studied, and this model is subjected to load, the resultant stresses will affect the light beam and these effects may then be observed. Methods are available for the determination of the values of the stresses, and the paths of the stresses, but these involve rather long mathematical calculations.

If celluloid is used, polarized light projected through it before the celluloid has been stressed will show a rather dark gray image. If tension is applied to the celluloid, the first color projected will be yellow. The slow increase of the tension will change the color from yellow to orange. A continued slow steady increase of the tension will change the orange to red, then to violet to blue to green. If the celluloid is continued to be stressed the projected color will turn from green to yellow and through the various colors of the spectrum in the order previously named. These series of spectra will continue as long as the celluloid is stressed until it breaks. Slow release of the tension will reverse the projected series of color. Thus, assuming that the tension is released while green is being projected, the color will change to blue to violet to red to orange to yellow.

The application of this method in the study of stress distribution of welded joints is accomplished by the cutting of celluloid models in exact replica of the welded joint to be studied. A sample is then inserted in the polariscope and polarized light projected through it onto a projection surface of screen. Stress is applied to the celluloid or screen model, and its distribution will be shown in the image projected. The intensity and concentration of the stress is indicated by the various spectral colors, as mentioned previously.

The study of stress distribution in welded joints by means of polarized light will reveal that the shape of the joint or part has a marked effect upon the distribution of stress.

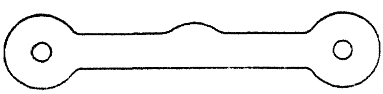


Fig. 117.

Fig. 118.

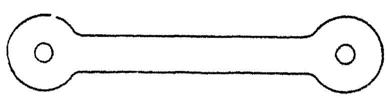


Fig. 119.

It will be found that in a heavily reinforced single vee butt joint the stress is localized at the edges of the bead and the top of the reinforcement carries practically no stress. Fig. 117 shows shape of celluloid model used for inspecting stress distribution in this type of

joint. If the reinforcement of the weld is reduced so that there is a less abrupt change in contour at the junction of the weld with base metal, as represented by the model, Fig. 118, it will be found that the distribution of stress is materially changed and the uniformity greatly increased. Further reduction of the reinforced portion of the joint, or rather, complete elimination of the reinforcement, as exemplified by the model, Fig 119 will cause a still more uniform distribution of stress.

The model, Fig. 120, represents a single vee butt joint with weld heavily reinforced but lacking complete penetration, causing a void at the bottom of the vee. A butt joint with overlapping welds is represented by the model, Fig. 121. The model, Fig. 120, when stressed and subjected to polarized light will show that there is a decided concentration of stress at the nick or unpenetrated portion of the joint. The model, Fig. 121, when stressed in a polariscope, will show stress concentration at the junction of weld metal at the surface of the base metal.

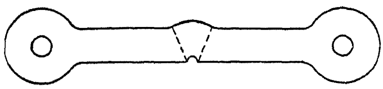


Fig. 120.

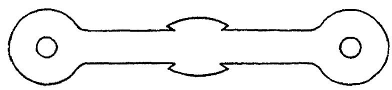


Fig. 121.

From the foregoing examples it can be readily understood that not only is workmanship an important item in matter of stress distribution but also costs are greatly affected. A heavy reinforcement carries very little stress; the deposited metal, which costs money to deposit, is not used to advantage. By greater uniformity of stress distribution, costs are reduced.

It might be well to think of the distribution of stresses as similar to the flow of water. Turbulence in the flow of the water can be avoided by gradually changing sections and by omitting irregularities, whether these irregularities be indentations or protuberances.

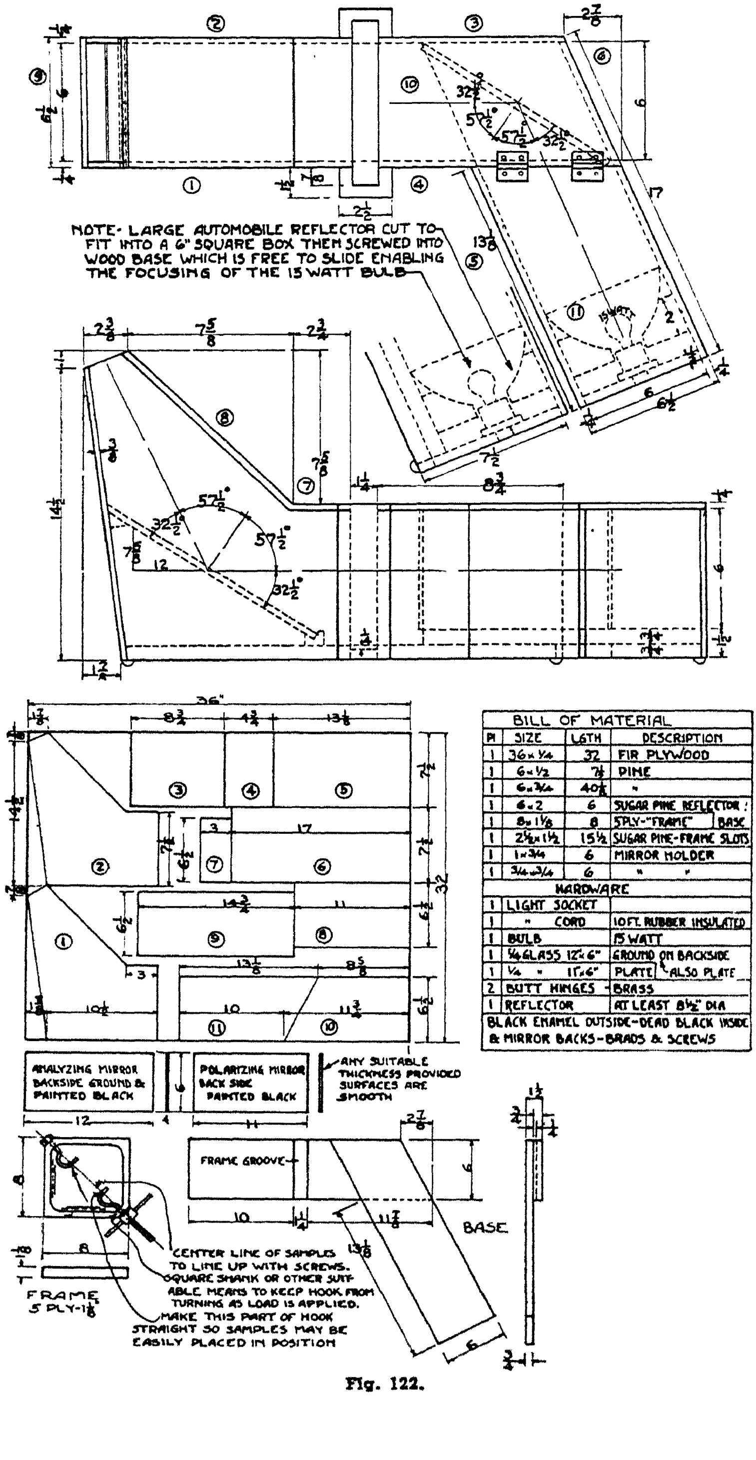
Notches, holes, incomplete penetration of welds, too much building up of welds, abrupt changes in cross-section and similar irregularities must and can be avoided easily.

In viewing these models under load, wherever lines crowd together or change direction abruptly, there is a point of high stress value.

The plan of a simple polariscope, easily and inexpensively constructed, is shown in Figs. 122 and 123. The dimensions are of a convenient size, but these may be varied, except the angular dimensions—that is the $57\frac{1}{2}°$ which must be maintained. In the one shown, an automobile lamp or a 15-watt 110-volt light bulb is used. This is placed in a reflector which is parabolic so the rays will be parallel.

The polarizer may consist of several sheets of thin glass or a single sheet painted black on the back. The analyzer is a single piece of glass ground and painted black on the back.

A model is placed in a loading frame so constructed that the load on the model may be varied. Tension is usually used as the



BILL OF MATERIAL

PI	SIZE	LGTH	DESCRIPTION
1	36 × ¼	32	FIR PLYWOOD
1	6 × ½	7½	PINE
1	6 × ¾	40⅛	"
1	6 × 2	6	SUGAR PINE REFLECTOR : BASE
1	8 × 1⅛	8	5PLY-"FRAME"
1	2½ × 1½	15½	SUGAR PINE-FRAME SLOTS
1	1 × ¾	6	MIRROR HOLDER
1	¾ × ¾	6	" "
	HARDWARE		
1	LIGHT SOCKET		
1	" CORD		10 FT. RUBBER INSULATED
1	BULB		15 WATT
1	¼ GLASS 12" × 6"		GROUND ON BACKSIDE
1	¼ " 11" × 6"		PLATE ALSO PLATE
2	BUTT HINGES		BRASS
1	REFLECTOR		AT LEAST 8½" DIA
BLACK ENAMEL OUTSIDE-DEAD BLACK INSIDE & MIRROR BACKS-BRADS & SCREWS			

Fig. 122.

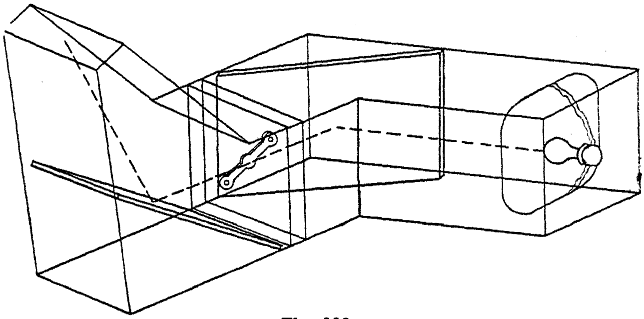


Fig. 123.

load condition. The frame with the model in place is inserted in the polariscope and observations are made as the load is varied.

Celluloid models of various types of welded joints under stress are shown in Figs. 124 to 127. Model of a riveted joint under stress is shown in Fig. 128.

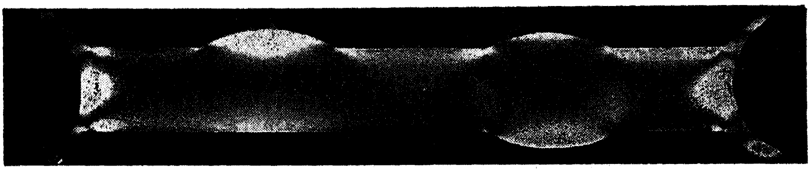


Fig. 124. Usual type of single vee and double vee joint. Even in the symmetrical double vee the stress distribution is not completely uniform, as it is in the straight section. The reinforcements are not carrying stress to the extent other sections are and therefore the metal of the joint is not used to advantage. Reduction of reinforcements would reduce costs and improve use of metal, making stress distribution more uniform.

Fig. 125. Comparison of the usual double vee with an abnormally reinforced double vee. Due to abrupt change in section of abnormal joint there are high stresses at the intersections of beads with plate, and the reinforcements carry very little stress. Note that the stress in center of bead or joint (the point of maximum area) is greater than the stress in the plate adjacent to bead. Result: poor use of metal and high cost, easily corrected by proper shape of joint.

Fig. 126. The crowding together of lines and quick change of their direction show most clearly the effect of undercutting (left). The stress is unevenly distributed. Correct procedure—Contrast this to the result shown on the right. Here, correct procedure avoids undercutting and gives uniform distribution as shown. Improves use of metal for better performance of the product.

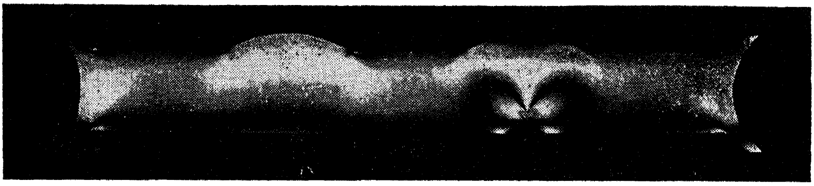


Fig. 127. Single vee of usual type compared to single vee with lack of fusion at root of vee. The crowding together of lines and the quick change of direction indicate high stresses, therefore poor use of metal. Properly made, the joint gives better performance, due to more balanced use of metal.

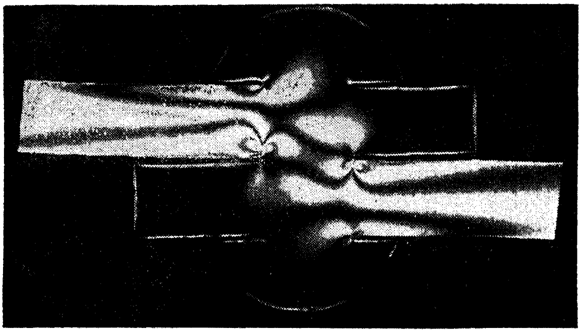


Fig. 128. Model of a riveted joint under stress.

EXPANSION, CONTRACTION, DISTORTION AND RESIDUAL STRESS

Expansion, contraction, distortion and residual or locked-up stresses are quite frequently considered as a group. It is well, however, to discuss them separately and then to consider their combination. The reason is because in some cases, it is desirable to study the effects of the individual factors. For example: The *external deformation,* or the going out of line or position often is troublesome and should be avoided or corrected. In some cases, too, locked-up stresses are useful, for example in shrink-fitting a locomotive tire to the wheel.

A number of factors affect these characteristics—rolling and forming of members; rigidity of members or structure; procedure of welding, involving the sequence of beads, number of passes and amperes used.

In order to anticipate results, the physical changes which take place and their sequence must be understood. A clear picture of these changes is provided by starting with simple illustrations and advancing step by step to the more complex examples found in practice.

A few physical laws should be kept in mind. These are:—

(a) Metals expand when heated and contract when cooled;
(b) Steel is elastic when stressed to a point slightly below its yield point. If stressed beyond the yield point, it "yields," resulting in a plastic flow of metal or permanent deformation;

(c) If a piece of low carbon steel is fully restrained from expanding longitudinally, an increase of 200° F. will cause it to be stressed beyond its yield point and cause a plastic flow of metal to take place.

(d) The yield point of steel changes with temperature, being quite low at the higher temperatures. As an example, the yield point may be 40,000 lbs. per sq. in. at room temperature and 20,000 lbs. per sq. in. at 1200° F.

Since steel is generally used in arc welding the discussion will refer specifically to steel.

To illustrate the physical changes which take place in steel during arc welding, we will assume two very narrow pieces of steel, 100″ long, are to be welded together as in Fig. 129, by adding an amount of weld metal that will be equal to the base metal. Two strain-gauge marks "a" and "b", are put on the side of the piece as indicated. For the purpose of explanation, it is assumed that sufficient molten metal is available in a ladle covered with slag to fill up the beveled out trough in one or two seconds, so that time will not be a factor; that the sides of the trough are fluxed in such a manner that the molten metal adheres to the sides forming a satisfactory joint with the base

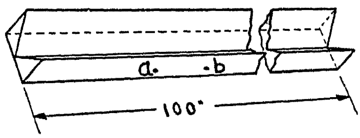


Fig. 129.

metal; that the temperature of the steel in the ladle is 2700° F.; that the strips are free to expand and that the small amount of base metal involved heats up uniformly. Within a very short time after the molten metal has been added, the base metal will have reached a temperature of approximately 1400° F. and will have increased in length to 101″ or an increase of about 1%. The weld metal will continually tend to cool and contract, but due to the low yield point of hot metal it is not capable of exerting any appreciable force on the structure until it has cooled below 1300° F.

If the metal is allowed to cool to room temperature, it will contract to its original length of 100″ and the points "a" and "b" will be the same distance apart as originally. Since the piece was not restrained while expanding or contracting, plastic flow did not take place and no distortion or residual stress resulted. The sample will then appear as in Fig. 130.

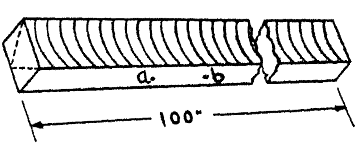


Fig. 130.

As a second step the same assumption as in Fig. 129 is made except that the sample is held in a rigid vice or clamp so that no longitudinal expansion can take place as in Fig. 131. If it is assumed that the beveled out trough is filled with molten metal in

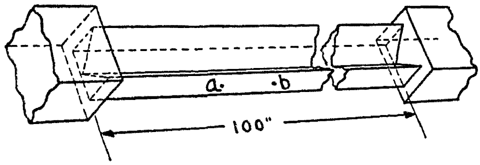


Fig. 131.

one or two seconds as described for Figs. 129 and 130, no longitudinal expansion can take place. Plastic flow of the base metal will occur as the base metal heats up to approximately 1400° F. As it cools to room temperature, the whole mass, weld metal and base metal, will contract without restraint to a length of about 99″ or one inch less than the original length. This condition is shown in Fig. 132.

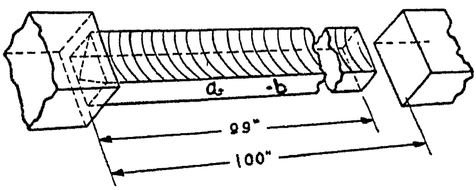


Fig. 132.

Since the metal has cooled uniformly, there will be no residual stress in the sample but the strain-gauge marks "a" and "b" will be 1% closer together than originally. Therefore, under such conditions strain-gauge readings, made before and after welding, cannot be used to determine residual stress.

It should be kept in mind that, as in the two cases above, the base metal adjacent to the weld metal first expands, or tries to expand, and then contracts while cooling.

As a next step, conditions shown in Fig. 133 are assumed. It will be noted that in the case of Fig. 133 the base metal on one side is a wide plate and on the other a narrow strip as in Figs. 129 and 131. Now the assumption is made that the beveled trough is filled with

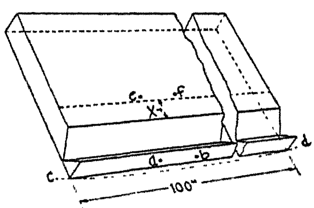


Fig. 133.

molten metal in one or two seconds as above. The base metal in Fig. 133 adjacent to the weld metal, will not reach as high a temperature as it did in Figs. 129 and 131 due to the greater mass of base metal in the plate of Fig. 133. Also the metal farther away from the weld will not become as hot as the metal near the weld. The hotter metal will expand more than the cooler metal. Therefore, colder metal will partially restrain the expansion of the hot metal near the weld, sufficient to cause some plastic flow of the metal near the weld. The width of the metal which was forced to undergo plastic flow is indicated by the letter "x". Therefore, in this case, there will be less expansion than in Fig. 129 but more than in Fig. 131 which was fully restrained from expanding. Consequently, the maximum expanded length of Fig. 133 will be some value greater than 100″, possibly 100.2″. During the expanding cycle, the plate will warp as indicated by the line c d. As this sample cools to room temperature, the metal adjacent to the weld metal, which was subjected to plastic flow, and the weld metal itself, will tend to contract to a value less than the original length, while that part of the base metal which was not subject to plastic flow during the heating cycle will tend to contract only to its original length. The result will be a stress set up in the sample. The edge nearest the weld will be longer than in Fig. 132 because it was restrained while contracting. The length of this edge after cooling will be estimated at 99.8″ and the plate will be warped as indicated by the line c d, Fig. 134. It will be noted that the plate warped in one direction while it was hot, Fig. 133, and in the opposite direction after it had cooled down to room temperature. Fig 134.

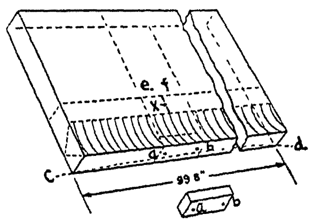


Fig. 134.

Since the weld metal and that part of the base metal which was subjected to plastic flow, indicated by width "x", is restrained from contracting by the metal outside this zone, the latter will generally be under compression stress and the metal within the zone "x" and the weld metal will be under tension stress. Strain-gauge measurements taken before and after welding at points "a" and "b" would show that these points have moved closer together. This is no indication of stress because the metal between these two points underwent plastic flow. Strain-gauge measurements taken at "e" and "f" may show these points have moved closer together. Since they were not in the zone where plastic flow occurred, this reading will be an indication of actual residual stress. The residual stress can be determined in the welded plate near the weld if strain-gauge measurements are taken after it has cooled to room temperature, and if a small section

surrounding the gauge marks is cut with a saw as indicated in Fig. 134 and if strain-gauge measurements are taken. The readings taken before and after cutting out the sample will indicate fairly accurately the stress in the sample cut out. Readings taken at "a" and "b" on the sample shown in Fig. 134 would probably show a further contraction of about .1% in the sample cut out if it was low carbon steel, indicating a stress approximately equal to the yield point of the metal. Stress can be similarly measured in other parts of the plate and the weld metal by taking strain-gauge measurements after cooling to room temperature and then cutting out small sections around each pair of gauge marks.

The next step will be to assume a pair of plates as indicated in Fig. 135. It is assumed that the beveled out trough is filled in one or two seconds as before. This plate will expand but the metal near the

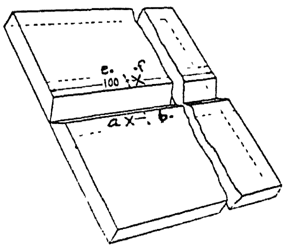


Fig. 135.

weld will be restrained, more so than in Fig. 133 because of the large mass of metal on each side of the weld. The maximum length will perhaps not exceed 100.1". A narrow zone on each side of the weld will undergo plastic flow. This zone is indicated by the letter "x". As this sample cools to room temperature, the weld metal and the base metal, which was subjected to plastic flow during heating, will tend to contract to a length less than the original, but will be restrained by the base metal outside the plastic flow zone which tends to contract only to its original length. Therefore, a residual stress will be set up and the final length of the welded plate, Fig. 136, will be greater than Fig. 134. It is estimated at 99.95".

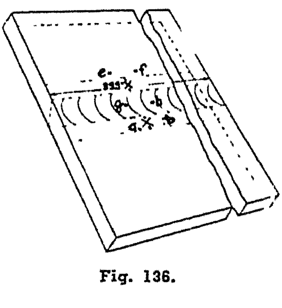


Fig. 136.

Strain-gauge measurements taken before and after welding at "a" and "b", Fig. 136, will not indicate the stress at this point because points "a" and "b" are in the zone which was subjected to plastic flow. Readings taken at points "e" and "f", outside the zone of plastic flow, will indicate the stress at this pair of points. If it is desired to determine the stress at "a" and "b", cut out around this pair of points as in Fig. 134 and again take strain-gauge measurements.

The residual stress can likewise be determined at the points "g" and "h" by taking strain-gauge readings after the specimen has cooled to room temperature and after cutting out the metal around these points as in Fig. 134.

Thus far, it has been observed that the base metal near the weld metal first expands then contracts. This is an important consideration to be kept in mind when determining what takes place under actual arc welding conditions. The weld metal continually contracts, but because of the low yield point of hot metal, it exerts relatively little force on the structure until it has cooled below 1200° F.

In actual arc welding the rate of advance is not as rapid as the assumption made of filling with molten metal so that there is an area expanding and an area contracting as illustrated in Figs. 137 and 138. Fig. 137 shows the condition as it exists when welding at relatively low speed

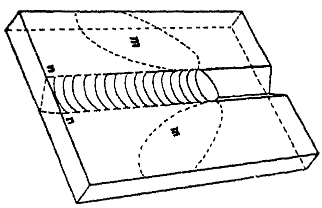


Fig. 137.

as with bare wire or small electrode. In this case, the expanding zone "m" is small or narrow in comparison to the width of the contracting zone "n." Therefore, the contracting zone is the predominating factor, causing the plates to close up ahead of the arc, the warping of the plates being in the same direction as indicated by line "cd" in Fig. 134.

Fig. 138 illustrates the condition as it exists when welding at relatively high speeds as with shielded arc type electrodes. In this case, the expanding zone "m" is relatively large and wide. Consequently, it is the predominating factor and causes the plates to open up ahead of the arc, warping being in the direction indicated by the line "cd" in Fig. 133.

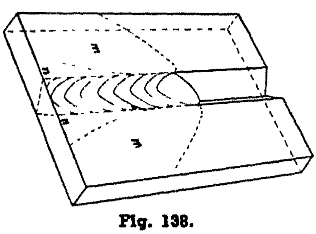


Fig. 138.

In either of the above cases after the arc welding has been completed, and the plate has cooled to room temperature, as illustrated in Fig. 139, the weld metal and the metal in the zone "x" which was subjected to plastic flow, are trying to contract but are being restrained by the base metal outside the plastic flow zone. Residual stress is, therefore, present in the arc welded plate as in Fig. 136. The residual stress in Fig. 139 may be determined as described for Fig. 136, that is, by taking strain-gauge readings after cooling to room temperature and then cutting out around the gauge marks with a saw and again measuring them. Strain-gauge readings, taken before and after welding, cannot be used to determine stress in that part of the plate which underwent plastic deformation during welding and the width of this zone cannot be readily determined.

It will be found that the weld metal and the base metal within the plastic flow zone indicated by "x" is in tension longitudinally and the base metal just outside the plastic flow zone is under compression stress

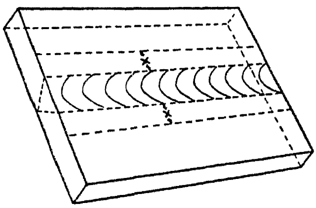


Fig. 139.

longitudinally. The stress in the transverse direction follows the same general laws but the final results are a little more complex due to the effect of the longitudinal stress on the structure. For example, the weld metal near the end of the plate in Fig. 139 may be under compression in a transverse direction and the weld metal near the middle of the plate may be in tension in the transverse direction. These results will vary with the size of the plates or structure. It is evident that some plastic deformation and residual stress in the arc welded structure is unavoidable. The manner in which these effects can be minimized is of interest.

It has been noted that during the arc welding operation, the metal adjacent to the weld first expands, then contracts. After cooling to room temperature, it remains in tension or attempts to contract further. If, after a short weld is made and allowed to cool until it has reached a state of maximum contraction, another weld placed next to it, will establish a transient expanding zone adjacent to it. The expanding zone will have less restraint and the contracting zone will be partially relieved. Thus the distortion has been minimized and the stresses have been reduced. This method of welding is called skip welding. (See Page 96.) A slightly more effective method is the skip-step-back method illustrated on Page 96. The greater the number of skips and the shorter the welds the more effective the method.

Some residual stresses will exist. It is evident that in 100% welds of the usual type these stresses cannot exceed the yield point, provided the weld metal has reasonably good ductility.

In considering what happens when a welded pressure vessel is loaded, Fig. 140 is taken. It is a section of a girth seam in a pressure vessel, with the zone "x" on each side of the weld subjected to plastic flow or plastic

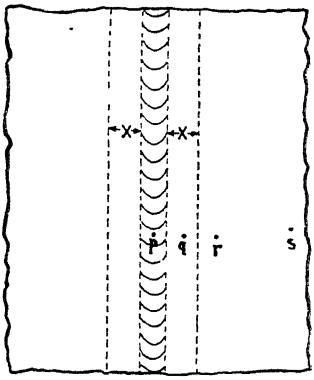


Fig. 140.

deformation during welding. It, therefore, has a residual stress equal to its yield point and the weld metal is stressed to its yield point before any pressure is put in the vessel. It is further assumed that the base metal of the tank has an ultimate strength of 60,000 lbs. per sq. in., and a yield point of 33,000 lbs. per sq. in., and that the weld metal has, in the as-welded condition, an ultimate strength of 63,000 to 65,000 lbs. per sq. in., and a yield point of 49,000 lbs. per sq. in. Since the load stress transverse to the weld in a girth seam, will be ½ that of the stress parallel to the girth seam, the stress in the parallel direction

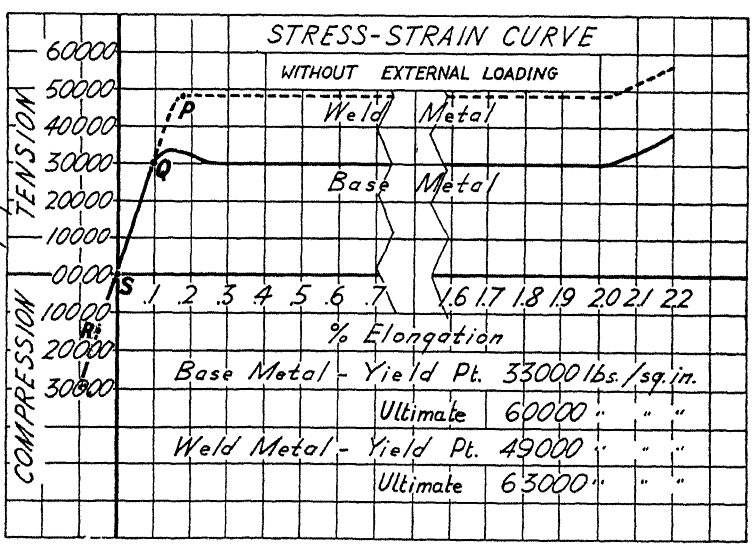


Fig. 141.

which is most liable to cause failure, is considered. Typical points are assumed as follows: "p" in the weld (Fig. 140), "q" in the plastic flow zone, "r" in the compression zone, and "s" in a neutral zone. It is further assumed that the weld metal at "p" has a residual stress of

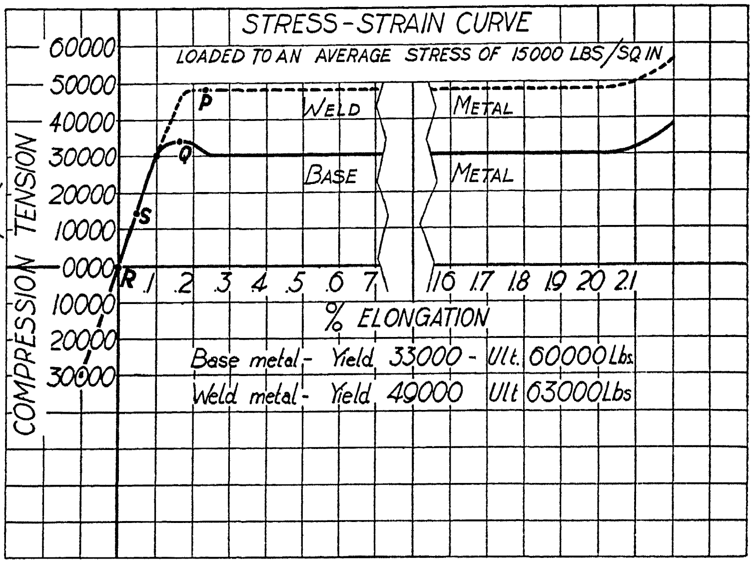


Fig. 142.

49,000 lbs. per sq. in., that the base metal at "q" has a residual stress of 30,000 lbs. per sq. in., that is, approximately equal to its yield point; that the metal at "r" has a residual compression stress of 15,000 lbs. per sq. in., and that the metal at "s" has no residual stress.

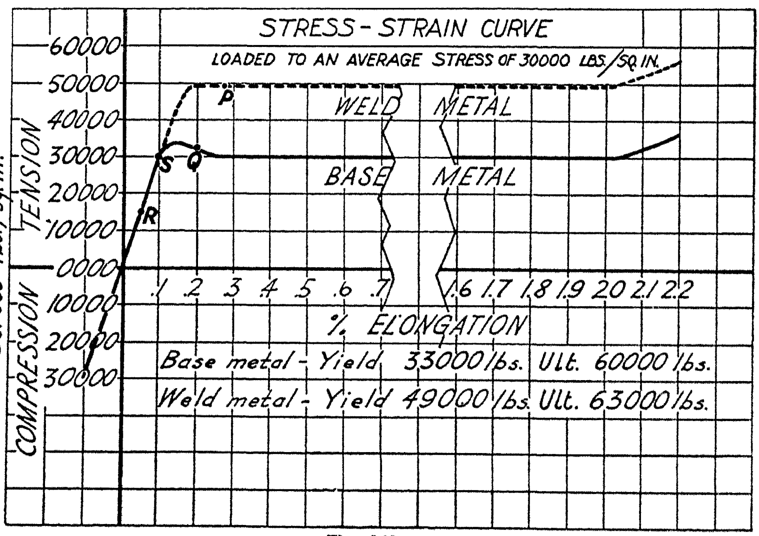


Fig. 143.

A typical stress-strain diagram may now be drawn for this type of steel and weld metal, and the stress can be indicated at points "p", "q", "r", and "s", as in Fig. 141, which shows the abscissa of an elongated scale so as to more clearly indicate the elastic portion of the curve. Fig. 141 shows the residual stress at the points indicated in Fig. 140 with no pressure in the vessel. Fig. 142 shows the stress at the same points with a pressure which would produce an average load stress of 15,000 lbs. per sq. in. It should be noted that the stress at points "p" and "q" did not increase appreciably as the load was applied and that the stress becomes more equally divided under load. Fig. 143 shows the stress at the same points when the pressure has been increased so as to produce an average load stress of 30,000 lbs. per sq. in., or nearly equal to the yield point

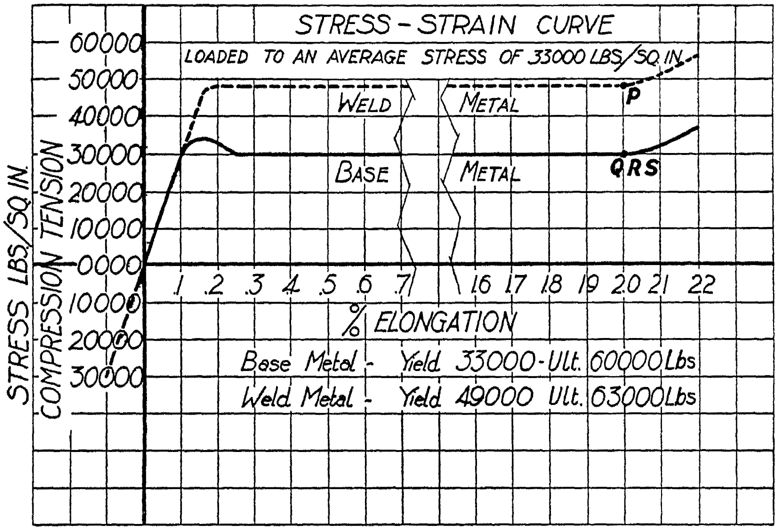


Fig. 144.

of the base metal. However, it should be noted that the stresses at points "p" and "q" have not increased appreciably. Both remain at approximately their respective yield points and safely below their ultimate strength. The load stress is more equally shared. Fig. 144 shows the stress at the same points after the pressure has been increased to bring the stress in the base metal of the vessel through its yield point. It will now be seen that the points "q", "r" and "s" have equal stress and that the stress in the weld metal differs from that in the base metal only by the difference in their yield points. Fig. 145 shows the residual stress at the points indicated after the load has been removed. It should be noted that "s" is zero, stress "p" has not become zero but is in tension placing "q" and "r" in compression to some slight degree as previously discussed. Here it will be noted that the vessel has been considerably stress relieved by increasing the load up to the yield point of the base metal. The remaining residual stress is less than the difference between the yield points of the base metal and the weld metal. This method of stress relieving pressure vessels has been called "mechanical stress relieving."

In this connection it should be borne in mind that any elongation must be accompanied by a proportional reduction of cross sectional area. The per cent reduction in area obtainable before failure depends upon the dimensions and amount of area involved. The maximum per cent reduc-

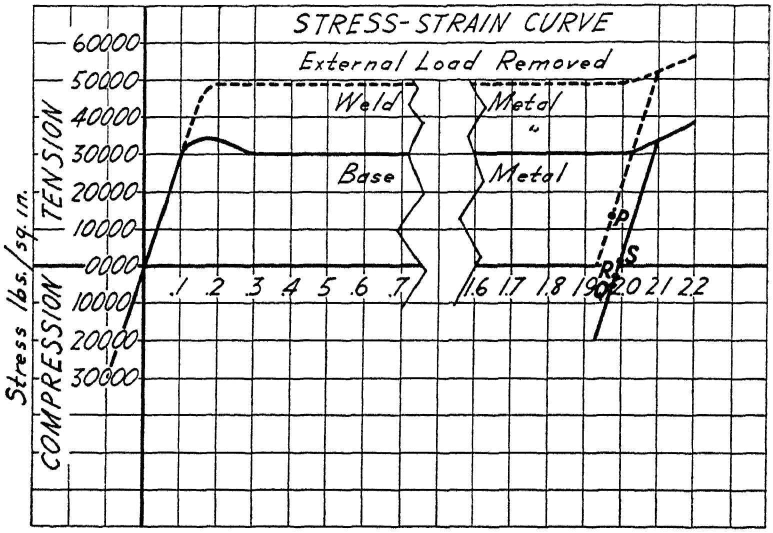


Fig. 145.

tion in area before failure is obtainable in a small cylindrical test piece in which reduction can take place equally along all diameters. In wide samples the percentage reduction in width is less and therefore the per cent reduction in area before failure is less. In very wide and relatively thick members the reduction in area can only take place along the "thickness" dimension and the amount along any dimension before failure is limited. Therefore the maximum elongation before failure varies inversely with the minimum dimension and cross sectional area involved.

From the foregoing it will be seen that dimensions have a bearing as to what sections are capable of yielding or elongating sufficiently to relieve the stresses and redistribute the load without failure. This may not be true in all cases such as very thick, wide sections. It may be necessary to heat stress relieve.

Opinions differ as to what thickness should be heat stress relieved. Experience indicates that the dividing line probably lies between one inch and two inch thickness and depends somewhat upon width, rigidity, etc.

This analysis indicates when the welded joint is a 100% joint, that is, where there is complete and adequate fusion in the finished joint, and the design is such that there is reasonably uniform load stress distribution, and both weld metal and base metal have good ductility, that no part of the vessel can reach a stress beyond the yield point until all parts of the vessel reach their yield points which are considerably beyond the usual working pressures.

Practical examples of the points discussed above are given as follows:

For one example, a bead six or eight inches long is deposited on a perfectly flat plate and allowed to cool. As it cools the bead will tend to

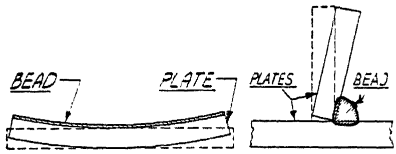


Fig. 146. Fig. 147.

Dotted lines indicate position before welding.
Solid lines indicate position after welding.

contract and if the plate is not too thick so that it can bend under the stress imposed and it is free to move, it will curve or bend up in the direction of the bead, see Fig. 146. A bead deposited from a small electrode with low current will cause very little warping due to the relatively small amount of metal which is heated to a high temperature. On the other hand a bead deposited from a large electrode with a high value of current so as to produce nearly complete penetration of the plate will cause very little warping in the direction indicated, due to the fact the metal at the bottom is also heated to a high temperature. There is a welding condition somewhere in between these two extremes that will produce a maximum warping in the direction indicated in Fig. 146.

Another example is when two pieces are welded together at right angles with a bead on one side. After the weld has cooled it will be found that the plates are not at right angles and the weld has pulled the pieces toward each other in the direction of the weld, as shown in Fig. 147.

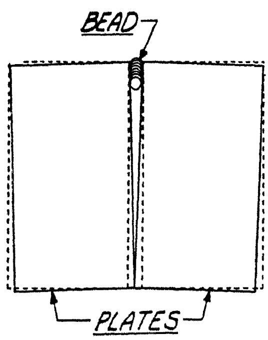


Fig. 148. Position of plates before welding is indicated by dotted lines. Solid lines show position after welding.

When two plates, with an opening between them, are welded with bare or washed electrode, the plates will draw together as the welding progresses. This is shown in the sketch, Fig. 148. The amount will depend upon the speed of welding. As a usual rule, the greater the speed,

the less the amount of the drawing effect. There can be found a speed at which the plates will not draw together.

When two plates have a tendency to draw together, the expedient of keeping a wedge in the seam 12″ to 18″ ahead of the welding proves very satisfactory. Allowance may be made for contraction if possible by separating the plates.

For usual plate thicknesses the plates should be separated approximately 1/8″ per each lineal foot of weld. The exact amount is difficult to state as it will vary with different jobs and conditions. Experience is the best teacher on this, and the above will serve as a guide.

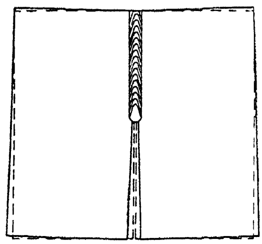


Fig. 149. Dotted lines show original position of plates. Solid lines indicate plates after welding at high speed.

If the welding speed is further increased as when using shielded arc electrodes, the plates will separate while welding proceeds as indicated in Fig. 149. In this latter case it will be necessary to tack or clamp the ends together before beginning the welding as shown in Fig. 151.

If a plate is veed for welding and then welded it will frequently be found that the plates will be drawn up as shown in the sketch, Fig. 150. This is true since the greater opening is at the top and more molten metal is deposited and a wider zone heated on this side, consequently there is more contraction.

The amount of warping will vary almost directly with the number of passes, being greater for a greater number of passes. This will also be true of the case shown in Fig. 147. In other words it is generally advisable to complete the weld with a minimum number of passes.

If the plates or parts welded are free to move there will usually be some distortion, and it must either be overcome or steps taken to reduce

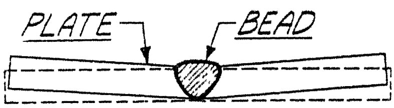


Fig. 150. Original position of plates is indicated by dotted lines. Position after welding is shown by solid lines.

the effect. When the parts are not free to move, that is, when the top of the vertical member shown in Fig. 147 is restrained the result is that the weld tries to pull it over, but since it cannot come, either the weld must stretch or the plates will bend. In the case shown in Fig. 151, if the weld-

ing speed is high the plates will tend to pull apart while welding is being done. However, after the plates have cooled down, it will be found that at both ends the plates are tending to press together and consequently the weld metal is under compression near the ends and in tension near the middle in the transverse direction. In the longitudinal direction, all the weld metal and the base metal, immediately adjacent to the weld, are under tension.

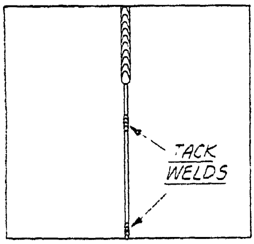
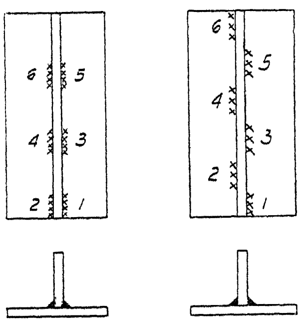


Fig. 151.

If the welding speed is slow the plates will tend to pull together while the welding is being done, but it will be found that after the weld has cooled down the direction of the stresses is in the same direction as described above.

It will be seen from the above that the stresses in a welded structure may have different directions and amplitudes while the welding is being done than after it has cooled down.

In heavy sections, that is, where welding is to be done on both sides, it is desirable to alternate welds, that is, put one bead on one side, then on the other. This tends to prevent distortion and balances the stresses.



Figs. 152 and 153. Examples of two sequences of welding often used to prevent accumulation of stresses and distortion.

Where the distortion will cause trouble it is desirable to make a study of the job and arrange the welds in a sequence that will keep it to a minimum. For example, if two pieces are to be welded at right angles, a sequence of welds as shown in Fig. 152 tends to reduce distortion. The

sequence may be varied to suit the job and some authorities recommend a sequence similar to that shown in Fig. 153.

Skip Welding is a very effective way to prevent distortion and reduce locked up stresses. This method consists in keeping the expanding zones sufficiently narrow and sufficiently close to the contracting zones so that they tend to stress relieve or neutralize each other. This can be accomplished by making a short weld, then skipping some distance ahead, making another similar short weld, etc. and then returning to the first weld and making another weld adjacent to it, etc. Sufficient time should elapse between making adjacent welds so that the first weld is sufficiently cool and is in contraction.

Step Back Method of Welding is a method of distribution of welds and procedure of making welds to help prevent the accumulation of stresses and distortion. This method consists not only of breaking up the welds in short sections but is dependent also upon welding in the proper direction, and this is illustrated in Fig. 154. The welds may be made in the sequence shown or may be broken up. For example, the welds may be made in the order of 1, 2, 3, 4, 5, 6, etc., or 1, 3, 5, 2, 4, 6, etc. The

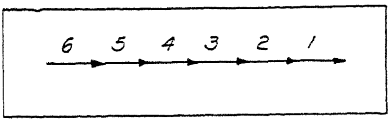


Fig. 154. Example of a procedure and sequence of welding by the step-back method.

latter is an illustration of the "skip-step back" method which is a combination of "skip" and "step-back" welding. In "skip-step back" welding, welds may be made in any convenient order.

Another method of reducing distortion or stresses is by peening. Still another method of reducing stresses is by heat, see Page 102.

It is impossible to give rules for controlling all forms of distortion and stresses, but it must be recognized that these are usually present in welding. Each job must be studied to determine the best procedure to follow for the method of welding employed.

These sketches and examples are, of course, somewhat exaggerated, so as to illustrate better the points under discussion.

As a summary of the subject the following general statements may be made:

1. Stresses are set up in plates and shapes by rolling, shearing, forming, etc. The partial release of these stresses during welding may be the controlling factor in the final amount of distortion that will occur.
2. Stresses and warping caused by welding can be divided into two classes.
   a. Stresses and warping that occur while the welding is in process. These are transient or temporary.

b. Final stresses and warping that remain after the welded members have cooled to normal temperature.

These two classes are somewhat different in magnitude and direction and both should be considered in the welding procedure. The amount of deformation or warping is not necessarily an indication of the value of the stress as the deformation depends on restraint, stiffness stress distribution and plastic flow.

3. All other things being equal an increase in speed will slightly increase the amount of warping.
4. On multiple pass welds the warping will increase as the number of passes increases.
5. Step-back welding will reduce locked-up stresses and warping. Skip welding will reduce locked-up stresses and warping due to the more uniform distribution of heat and the greater rigidity of the seam during the welding process.
6. It is always desirable that the direction of welding be away from the point of restraint and toward the point of maximum freedom. In other words, weld away from a welded seam at right angles to the welding.
7. Clamping will reduce warping and is more effective when the welded members are allowed to cool in the clamps. However, clamping will not entirely eliminate warping.
8. Peening is an effective method of reducing stresses and partly correcting distortion or warping.
9. Stresses may be relieved by heat treatment.
10. Stresses may be relieved by mechanical loading.

Following are a few practical examples in line with the above discussion.

Fig. 155 shows a bearing bracket made of an angle rolled into a circle, a centre tube connected to the angle by formed arms.

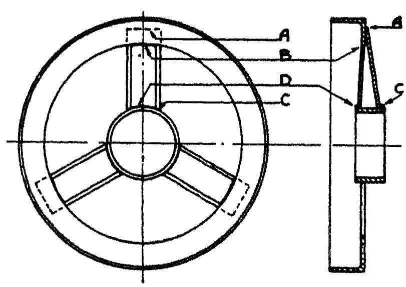


Fig. 155.

Welds A and B should be made on each arm and allowed to cool, since the arms are free to move they will adjust themselves. Then welds C and D should be made. However, welds should be made in the order A-C, D-B.

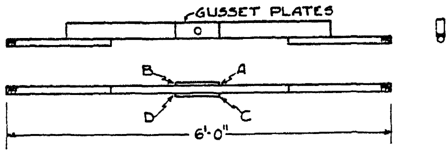


Fig. 156.

A similar case is shown in Fig. 156. Welding A-B-C-D in order given caused distortion. When A and C were made, the weld allowed to cool — then B and D were made the result was satisfactory.

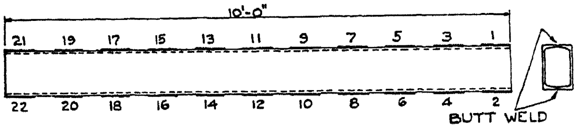


Fig. 157.

Another interesting case is shown in Fig. 157. This comprises two 6-inch channels welded together to form a rectangular tube. For minimum distortion a light tack bead is placed at 11 and 12, then 1 and 2, then 21 and 22. The welding sequence, with step-back method is: 1-2; 5-6; 9-10; 13-14; 17-18; 21-22; 3-4; 7-8; 11-12; 15-16; 19-20. This minimizes distortions — usually keeping it less than 1/8 inch. (See Item 5, Page 97.)

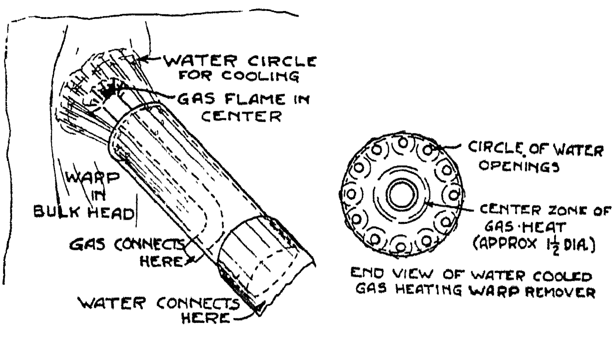


Fig. 158.

An interesting example of distortion correction is the case of a bulkhead which warped. A torch, equipped with water spraying device heats a spot about 1½ inch in diameter, in the centre of the spray. (See Fig. 158). The spray keeps the surrounding plate cool, the centre portion reaches a plastic stage, then the locked-up stresses upset the heated metal resulting in release and redistribution of local stresses. The contraction of the upset metal pulls the plate into shape. Repeated applications may be required if the plate is large or badly distorted. (See Item 1, Page 96.)

Another similar example is the case of a bent I beam (or similar section). If the longer flange (convex side) and part of the web are heated,

the metal expands and due to restraint of adjacent cooler sections is upset. Upon cooling, the heated metal contracts and pulls the beam into shape. Repeated applications may be required.

A counter or opposing effect is sometimes useful. For example, in welding stiffener plates on girders, considerable warpage may result. This can be minimized by welding both sides at the same time, the welders working opposite each other using the skip method.

Counter distortion is often made use of, in erecting a pipe railing. By giving the pipe a slight reverse bend prior to welding and by blowing air through the pipe after welding, the railing straightens itself. This procedure is usually more simple than straightening operations after erection of the railing.

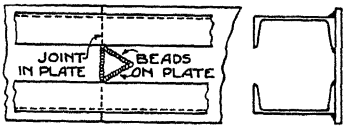


Fig. 159.

Another interesting example is that of two channels welded to a plate. (See Fig. 159). Trouble was encountered due to breakage in the transverse joints of the plate shortly after welding, due to excessive restraint. (See Item 6, Page 97). By running short beads on the plate so as to lift the plate slightly at the transverse joint this difficulty was corrected, due to a better distribution of locked up stresses.

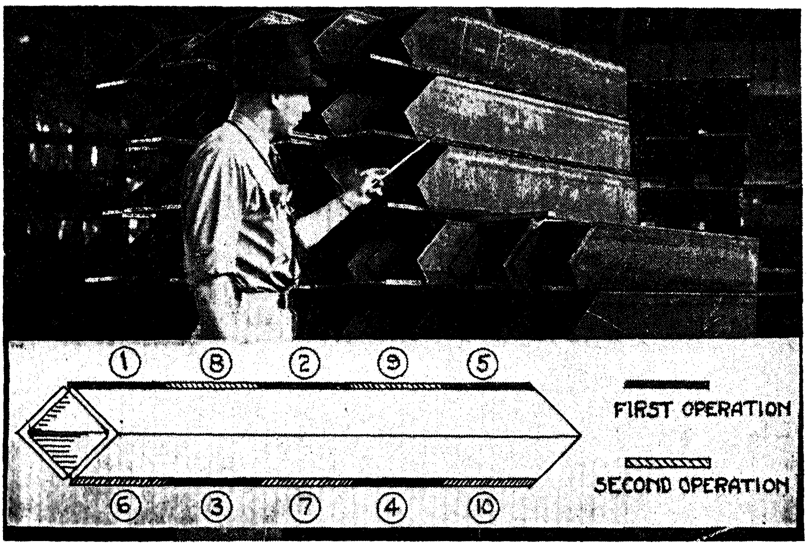


Fig. 160. These box beams were welded from angles according to the sequence shown in the inset.

In assembly of a part involving several components, it is advisable to keep in mind the suggestion of Item 6, Page 97. Weld from the point of restraint, allow the parts to adjust themselves as welded. For example in a girder the butt joints of flanges and web plates are made

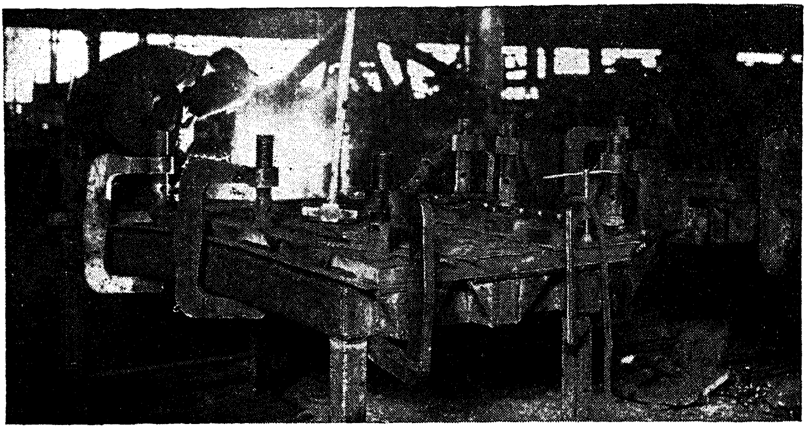


Fig. 161. Bottom of earth scraper. Parts to be welded are clamped to a work table with a certain amount of pre-camber to offset warpage.

separately. Any additional parts such as flange cover plates, stiffeners and shelf angles on webs, etc. should be welded in place before webs and flanges are assembled. If floor beams are to be connected to the girder by welding, the effect of these joints must be considered, as in general they produce the same effect as the welding of web stiffeners.

The above examples illustrate the control of distortion which is

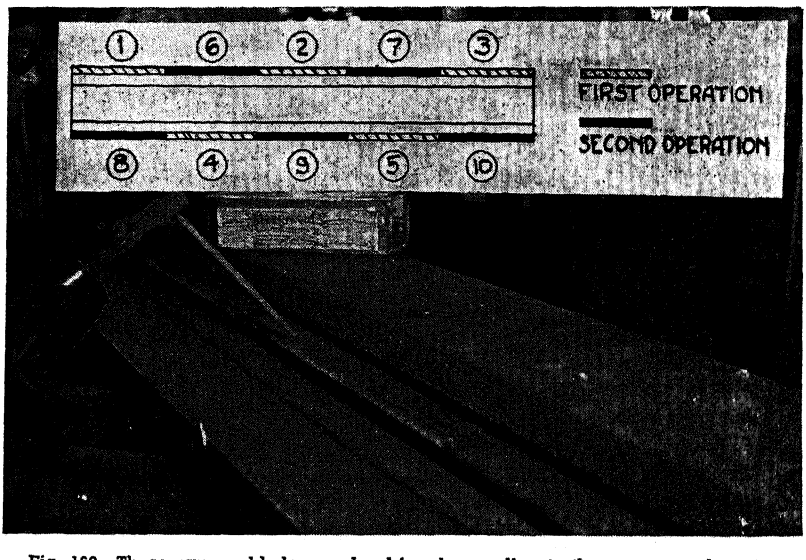


Fig. 162. These scraper blades are hard-faced according to the sequence plan shown in the inset sketch.

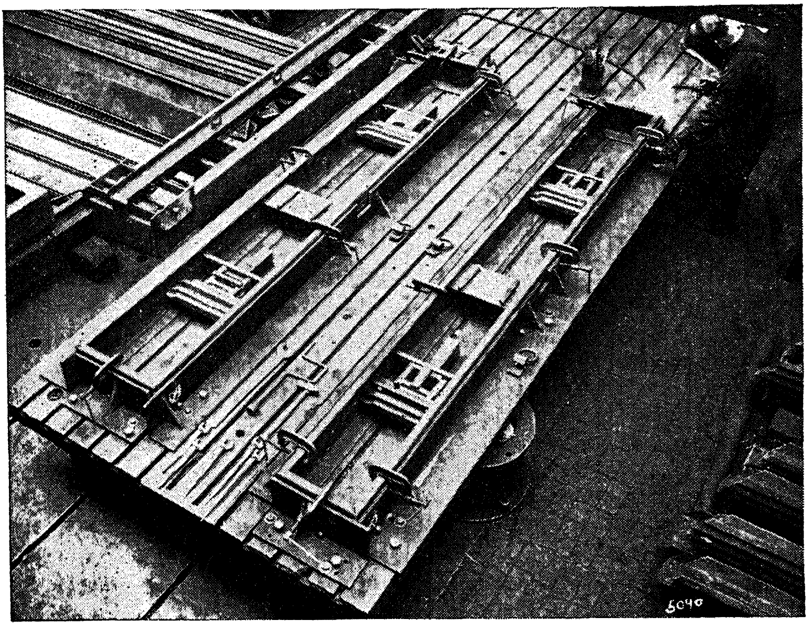


Fig. 163. Fixture for welding bulb angle frame for coke oven self sealing doors maintains proper alignment of parts.

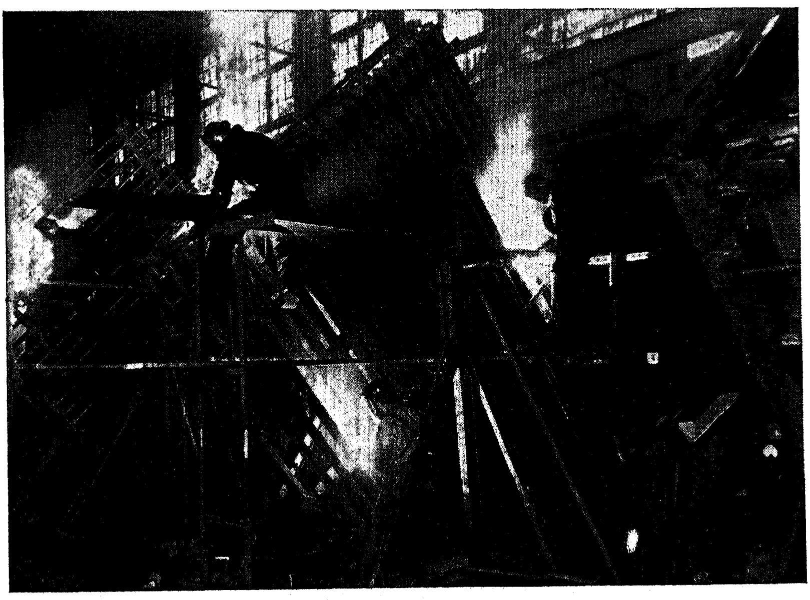


Fig. 164. Trash racks for dam. Size 12′ x 10′. Fixture holds parts with pre-camber to keep finished shape within 3/8″ of true plane.

possible, when proper account is taken of the effects of the heating and cooling of metal.

Stress Relieving.—Stress relieving may or may not be necessary, depending upon the design requirements of the finished structure. In a great many cases stress relieving is not necessary. In some others a proper peening of the weld may be sufficient; and again in other cases stress relieving by heating may be essential. In cases where stress relieving is required, the types of work involved may be divided into three general classes, namely: (1) Welded repairs of broken parts and miscellaneous small jobs; (2) machinery units; (3) pressure vessels built in conformance to A.S.M.E. Boiler Code. (See Page 106).

Stress relieving of work designated in classification (1) may be accomplished by heating the work to slightly above 1100 degrees F. and then allowing the work to cool slowly. Cooling may take at least 10 or 12 hours and in many cases 24 hours of cooling are desirable. In the case of large castings of complicated shape, they may be cooled for as long as two days. Small pieces, such as butt welded high speed tool tips, may be satisfactorily annealed by putting the tool immediately after welding into a box of powdered asbestos and allowing it to cool for 24 hours.

Where available a furnace should be used for heating. If no furnace is at hand, a temporary one may be built with fire brick without cement. A charcoal or coke fire or gas or oil torch may be used to supply the heat. After the proper temperature has been reached the furnace should be closed and allowed to cool slowly. If charcoal or coke has been used, the work should be covered with ashes and embers when cooling. Sometimes the work is covered with clean sand or slaked lime to retain the heat as long as possible. Asbestos sheets may also be employed for this purpose.

Stress relieving of machinery units may or may not be required. In many cases a mechanical stress relieving by peening each layer preferably with compressed air and a roughing or peening tool is entirely satisfactory.

In some cases where heavy plates or a heavy welded section is used or where the assembly is subjected to severe loads and stresses it may be desirable or necessary to stress relieve by heating. In this case the information given later from the A.S.M.E. Boiler Code will prove helpful.

On heavy plates it may be necessary to stress relieve before weld is entirely completed. It is usually regarded as good practice to stress relieve after deposit of weld metal has been made to approximately 1½" depth and for each 1" to 1½" additional thickness of weld metal.

For stress relieving pipe and certain welding work there are available on the market welding generators of higher frequency than that obtained from usual power supply (ranging up to several times line frequency). These generators, in combination with proper coil and equipment, provide a practical method of stress relieving where it is required. Here, the stress relieving generator also serves as the welding apparatus and eliminates the need of special stress relieving transformers.

QUALIFICATION OF WELDERS

There is some mystery about the terms "certification" or "qualification" of welders. Many people seem to think that there is some all-inclusive set-up by which a welder can take tests and become a certified welder from there on, for all kinds of work, anywhere. This is not true.

Tests to determine the abilities of welders to do a certain kind of work are conducted by many independent laboratories. The ability of a welder to do work of these specific grades is then certified. However, this is not a general certification but a certification for a definite type of work or employer, and for a specified time.

The following suggestions pertain to quick, low-cost methods of selecting welders who would later be able to take more detailed tests such as for A.S.M.E. requirements, etc., if required. They also serve as quick and low-cost tests for selection of welders for most general classes of work, except that specified by certain codes.

No standard set of tests for the qualification of welder operators can be devised which is applicable for all types of work. For example, the quality of welding required in a small underground storage tank is not of as high a value as the quality of welding required in the construction of pressure vessels. Therefore it is impractical to require operators to qualify for U-68 or U-69 (A.S.M.E. Boiler Code—see Page 106) welding when such quality is not required.

It should be borne in mind that qualification tests of operators should not be confused with qualification tests of electrodes.

Qualification tests should be devised simply on the basis of quality required in actual construction operations. Operators should be tested in making all types of welds usually encountered in the regular line of the particular shop's work. These tests should be so set up that they will as closely as possible approximate the same conditions as are actually encountered in production welding.

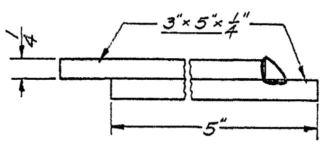


Fig. 165.

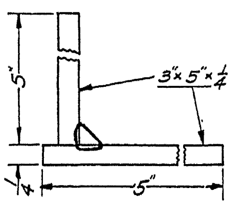


Fig. 166.

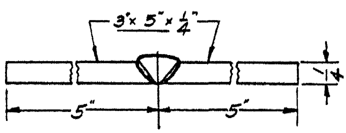


Fig. 167.

Qualifying tests should be such as would qualify the operator for the particular work which he will have to do, and should not impose upon the welder a quality greater than is necessary to meet the design requirements.

A series of test pieces such as those illustrated herewith serve to qualify operators for most of the ordinary applications of welding. A lap weld made in a flat position (see Fig. 165) will reveal a great deal about an operator.

There should be good penetration to the root of the weld and good fusion at both sides of the bead. Examination for these requirements can be made by breaking the weld through the throat.

If the operator fails to pass this test he is disqualified. If he does pass it the qualification tests can be continued by making a fillet weld, Fig. 166. This would be judged on the basis of absence of undercutting, shape of the bead, lack of overlap, and proper fusion, as shown by fracture or bending of the test piece. The next test should be a butt weld made in a flat position (see Fig. 167). The weld should show good fusion without overlapping or undercutting.

After this test specimen has been examined for external condition of bead, it should be given a nick-break test. Two saw cuts, in line, and approximately at the center of the weld, will cause the joint to break through this weakened section when specimen is subjected to a sharp blow of sufficient intensity. Examination of the fracture will disclose the quality of the deposited metal. (See nick-break test, Page 267.) The deposited metal should show uniform structure, be free of slag inclusions, have no porosity and be completely fused. There may be some variation in color due to the variety of stresses set up by application of the blow.

Another excellent and inexpensive test is a double butt strap joint. Welds are placed along the sides of the straps, but not extending to the ends. The specimen is prepared in this way so as to place the welds in longitudinal shear only, without any parts in transverse shear. This results in a single load condition. The tongue or pull bars and straps should be of such size in reference to the welds as to cause failure to occur in the welds. The usual precedure followed in the shop can be used. The joint is subjected to a load and broken, failure generally starting at one end of a weld. The weld is accurately measured and the ultimate value of the joint determined. This figure is then compared with the figure for a perfect joint and the operators rated accordingly.

As an illustration of the method used by a prominent structural steel fabricator to test operators for heavy structural work, a butt joint is made up as shown in the sketch Fig. 168. The joint is made by joining two pull bars by butt straps. The pull bars are 1" thick, 4" wide and 12" long. A space of ½" is left between the connected ends of the pull bars. The beads, each having approximately 2½" effective length, are in longitudinal shear and since the beads are approximately ⅜", the ultimate

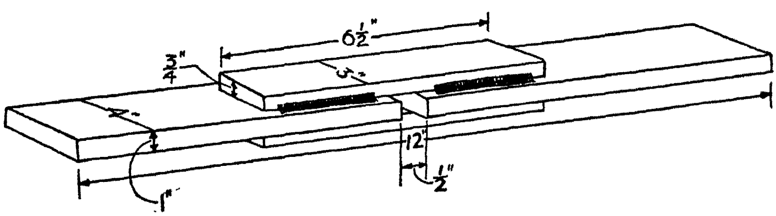


Fig. 168.

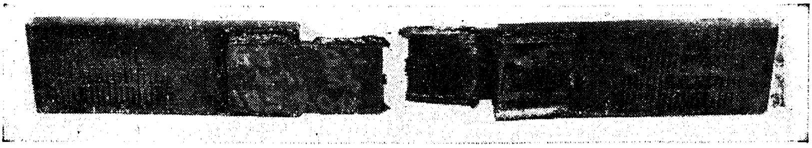


Fig. 169-A

strength of the joint is practically 200,000 lbs. As evidence of improvement in operator's skill, joints of the type mentioned failed at 120,000 lbs. only a few years ago. Due to correct instruction, adequate and continued inspection, the value increased first to 140,000-160,000 lbs. then to 170,000-185,000 lbs. The test specimen shown in Fig. 169-A was pulled to 185,000 lbs.

A further test of welded joints is the comparison in strength between a welded (left) and riveted (right) single butt connection as shown in Fig. 169-B. The riveted connection utilized ¾″ rivets and drilled holes and was made in such a way as to be superior to the usual field-riveted joint. Yet failure occurred at 96,000 lbs., or 32,000 lbs. per

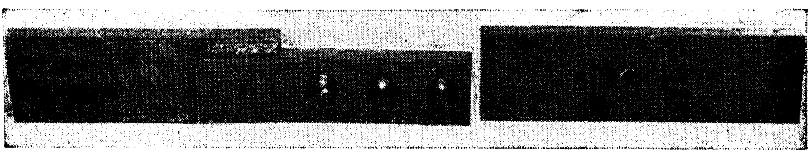


Fig. 169-B.

rivet. The result of shear action on the rivets and the plate can be clearly seen. Both are distorted or given a permanent set. A study of the welded connection, keeping in mind that the load is eccentric, demonstrates the welded joint's superiority.

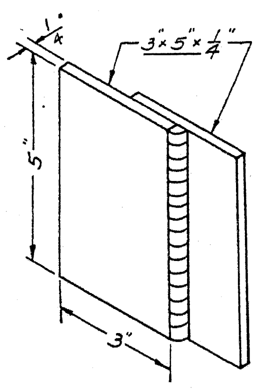


Fig. 170.

If the work for which the operator is to be qualified requires vertical welding, then the tests should be made welding the aforementioned joints in vertical position. For example, a typical test specimen of a vertical lap weld is shown in Fig. 170. If the work requires welding a joint in a "hard to get at" position then the test should simulate such positions. A typical example of such a condition is illustrated in Fig. 171 which shows a test weld of a vertical lap joint which requires greater skill on the part of an operator to make a satisfactory weld than the test, Fig. 170. Obviously it is unnecessary to test an operator under conditions presented in Fig. 171 unless such conditions are actually encountered in the work for which the operator is required to qualify. If overhead welding is also required, then the tests should be continued to include welding the same types of joints in the overhead position as mentioned previously.

In all cases it must be remembered that the purpose of the qualification test is to ascertain the ability of the operator to make a good joint in the field; not just a good test specimen. An operator who makes good test specimens will usually make good field specimens. This has been brought

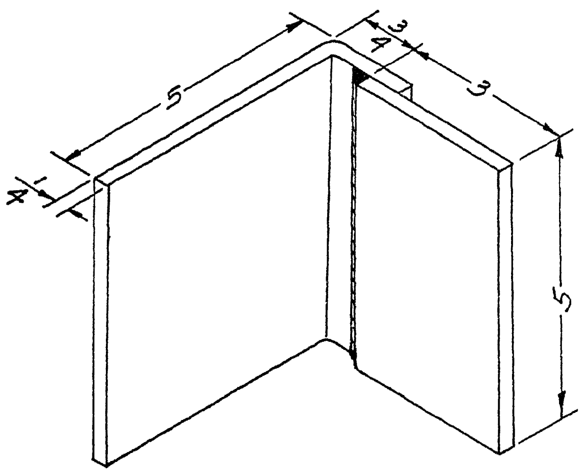


Fig. 171.

out in a number of cases where comparative checks on test and field specimens were made. The ability and skill of the operator as indicated by test specimens generally produces these same results in the field work.

The American Welding Society, 33 West 39th St., New York City, has issued a bulletin, "Testing and Qualification of Welding Operators" which is available at a small cost.

A.S.M.E. CODE FOR UNFIRED PRESSURE VESSELS

The following rules pertaining to the use of the fusion welding process in the construction of unfired pressure vessels are those established by the American Society of Mechanical Engineers.

Rules for the Fusion Process of Welding

U-67 Pressure vessels may be fabricated by means of fusion welding provided the construction is in accordance with the requirements for material and design of the rules for fusion welding as required in this code.

DEFINITIONS

a *Fusion Welding.* A process of welding metals in the molten, or molten and vaporous state without the application of mechanical pressure or blows.

b *Fillet Weld.* A fusion weld of approximately triangular cross section the throat of which lies in a plane disposed approximately 45 deg. with respect to the surface of the parts joined.

c *Throat.* The minimum thickness of a weld along a straight line passing through the bottom of the cross-sectional space provided to contain a fusion weld.

d *Double-Welded Butt Joint.* A joint formed by the fusion of two abutting edges with a filler metal added from both sides of the joint and with reinforcement on both sides.

e *Single-Welded Butt Joint.* A joint formed by the fusion of two abutting edges with all the filler metal added from one side of the joint with a reinforcement on the side from which the filler metal is added.

NOTE: A joint with filler metal added from only one side is considered equivalent to a double-welded butt joint when and if means are provided for accomplishing complete penetration and reinforcement on both sides of the joint.

U-68 Vessels covered by this code may be used for any purpose when constructed in accordance with the rules given in this paragraph.

The joint efficiency *E* to be used in applying the rules in Par. U-20 shall be taken as 90 per cent.

The welding shall meet the following test requirements:

Test Plates. *a* Two sets of test plates of the dimensions shown in Fig. 173 from steel of the same specifications and thickness as the shell plates, prepared for welding, may be attached to the shell plate being welded, as in Fig. 172, one set on each end of one longitudinal joint of each vessel so that the edges to be welded in the test plates are a continuation of and duplication of the corresponding edges of the longitudinal joint. In this case the weld metal shall be deposited in the test plates continuously with the weld metal deposited in the longitudinal joint. As an alternate method, detached test plates may be welded as provided for in (*b*). The plates for test samples may be taken from any part of one or more plates of the same lot of material that is used in the fabrication of the welded vessels and without reference to the direction of the mill rolling.

b When test plates are welded for the longitudinal joints none need be furnished for circumferential joints in the same vessel provided the welding process,

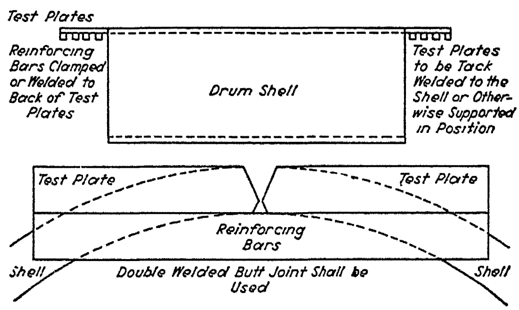


Fig. 172. Method of forming longitudinal test plates.

procedure and technique are the same. Where a vessel has only circumferential joints, two sets of test plates of the same material as the shell shall be welded in the same way as the joints in question.

When noncylindrical pressure parts are not integral with the drum or shell, the two test plates, of a thickness not less than that of the parts, shall be provided.

c. When there are several vessels being welded in succession or at any one time the plate thicknesses of which fall within a range of ¼ in., each 200 ft. of longitudinal and circumferential seams may be considered as the equivalent of one

vessel and only the test plates required by (a) and (b) need be made, provided they are welded in the same way as the joints in question. The test plates shall be so supported that warping due to welding shall not throw the finished test plate out of line by an angle of over 5 deg.

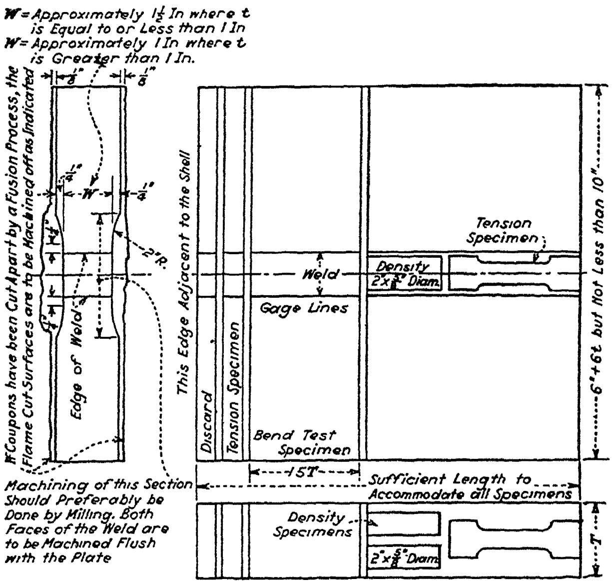


Fig. 173. Test specimen from longitudinal welded test plates.

Where the welding has warped the test plates they shall be straightened before being stress relieved. The test plates shall be subjected to the same stress-relieving operation as required by Par. U-76. At no time shall the test plates be heated to a temperature higher than that used for stress relieving the vessel.

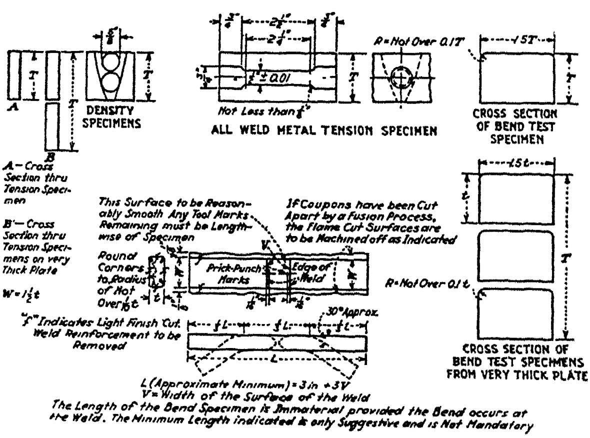


Fig. 174. Details of test specimens.

d Test Specimens. The inspector shall select one of the two welded test plates from which the coupons for tension and bend tests and for specific-gravity determinations shall be removed as shown in Fig. 173 and be of the dimensions shown in Figs. 173 and 174.

e Tension Tests. Two types of tension-test specimens are required, one of the joint and the other of the weld metal. The tension specimen of the joint shall be transverse to the welded joint, and shall be the full thickness of the welded plate after the outer and inner surfaces of the weld have been machined to a plane surface flush with the plate. When the capacity of the available testing machine does not permit testing a specimen of the full thickness of the welded plate, the specimen may be cut with a thin saw into as many portions of the thickness as necessary, each of which shall meet the requirements.

The tensile strength of the joint specimen in Fig. 173 shall not be less than the minimum of the specified tensile range of the plate used. (The tension test of the joint specimen as specified herein is intended as a test of the welded joint and not of the plate.)

The tension-test specimen of the weld metal shall be taken entirely from the deposited weld metal and shall meet the following requirements:

Tensile strength = at least that of the minimum of the range of the plate which is welded;

Elongation, minimum = 20 per cent in 2 in.

For plate thicknesses less than $\frac{5}{8}$ in., the all-weld-metal tension test may be omitted.

f Bend Tests. The bend-test specimen shall be transverse to the welded joint of the full thickness of the plate and shall be of rectangular cross section with the width $1\frac{1}{2}$ times the thickness of the specimen When the capacity of the available testing machine does not permit testing a specimen of the full thickness of the welded plate the specimen may be cut with a thin saw into as many portions of the thickness as necessary, each of which shall meet the requirements. The inside and outside surfaces of the weld shall be machined to a plane surface flush with the plate. The edges of this surface shall be rounded to a radius not over 10 per cent of the thickness of the plate. The specimen shall be bent cold under free bending conditions until the least elongation measured within or across approximately the entire weld on the outside fibers of the bend-test specimen is 30 per cent.

When a crack is observed in the convex surface of the specimen between the edges the specimen shall be considered to have failed and the test shall be stopped. Cracks at the corners of the specimen shall not be considered as a failure. The appearance of small defects in the convex surface shall not be considered as a failure if the greatest dimension does not exceed $\frac{1}{16}$ in.

g Specific Gravity of Weld Metal. Specimens shall be taken from the weld metal of the joints. The specific-gravity specimens shall, if possible, be 2 in. long and $\frac{5}{8}$ in. in diameter, as shown in Figs. 173 and 174. The minimum specific gravity shall be 7.80.

h Retests. Should any of the tests other than the specific-gravity tests fail to meet the requirements by more than 10 per cent, no retests shall be allowed.

Should any of the tests other than the specific-gravity tests fail to meet the requirements by 10 per cent or less, retests shall be allowed on specimens cut from the second welded test plate.

The retests shall comply with the requirements. For either of the tension retests, two specimens shall be cut from the second test plate, and both of these shall meet the requirements.

When there is more than one specimen of the same type and when one or more of the group specimens fail to meet the requirements by 10 per cent or less, the retest shall be made on an entire group of specimens which shall meet the requirements.

Should the specific gravity obtained on the specific-gravity specimen be less than 7.75, no retest shall be allowed. Should the specific gravity lie between 7.75 and 7.80, a retest shall be allowed. The retest shall show a specific gravity of not less than 7.80.

i Non-Destructive Tests. All longitudinal and circumferential welded joints of the structure shall be examined throughout their entire length by the X-ray

or the gamma-ray method of radiography. In case the wall thickness exceeds 5¼ in., and until such a time as evidence is submitted to the Boiler Code Committee that greater thicknesses can be commercially examined, the joints shall be stress relieved and then radiographed when the thickness of the metal deposited in the weld is 5¼ in. The joints shall also be stress relieved after the completion of the welded joint.

All welded joints to be radiographed shall be prepared as follows: The weld reinforcements on both the inside and outside shall be ground, chipped and ground, or suitably machined to remove the irregularities of the weld surface so that it merges smoothly into the plate surface. The finished surface of the reinforcement may have a crown of uniform amount not to exceed approximately 1/16 in. Single-welded butt joints made the equivalent of double-welded butt joints, in accordance with Par. U-73*a*, may be radiographed without removal of backing-up strip, provided the backing-up strip image will not interfere with the interpretation of resultant radiographs.

The films obtained by the use of X rays shall be known as "exographs," and those obtained by the use of gamma rays as "gammagraphs." Both types of films shall be generally termed "radiographs."

The weld shall be radiographed with a technique which will determine quantitatively the size of defects with thicknesses equal to and greater than 2 per cent of the thickness of the base metal. To determine whether the radiographic technique employed is detecting defects of a thickness equal to and greater than 2 per cent of the thickness of the base metal, suitable thickness gages or penetrameters shall be placed on the side of the plate nearest the source of radiation and used in the following manner:

(1a) A penetrameter of the type shown in Fig. 175 shall be placed at each end of the exposed portion of the weld with the penetrameter parallel to the weld and at least ¼ in. from the edge of the weld. Two ranges of penetrameters shall be available; these shall be stepped as follows: 0.005 to 0.04 in. for plate thicknesses up to 2 in., and 0.04 to 0.105 in. for plate thicknesses from 2 to 5¼ in., as shown in Fig. 175. In every case the thickness gages or

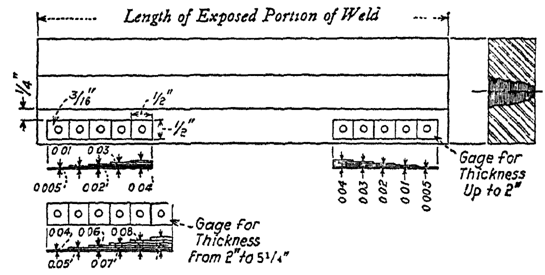


Fig. 175. Details of thickness gages or penetrameters.

penetrameters should be so placed that the thin edge of the gage will be adjacent to the end of the exposed section of the weld.

The film during exposure shall be as close to the surface of the weld as is practicable. The distance of the film from the surface of the weld on the side opposite the source of radiation shall, if possible, not be greater than 1 in.

With the film not more than 1 in. from the weld surface the minimum distance between the source of radiation and the back of the weld shall be as follows:

Plate thickness in.	Minimum distance from source of radiation to back of weld in.
Up to 1	14
1 to 2	21
2 to 3	28
3 to 4	36
4 to 4¼	38

There should also be a plain indication on each film showing the job number, the drum and seam, as well as the manufacturer's identification, symbol or name.

If it is necessary to expose the film at a distance greater than 1 in. from the weld, the following ratio of:

$$\frac{\text{Distance from source of radiation to weld surface toward radiation}}{\text{Distance from weld surface toward radiation to film}}$$

shall be at least 7 to 1. When a grid of the Buckey type is employed to reduce scattered radiation, the above ratio may be reduced to five. These conditions are imposed so as to limit the allowable distortion and magnification of any defects in the welded seam.

All radiographs shall be free from excessive mechanical processing defects which would interfere with proper interpretation of the radiograph.

Identification markers, the images of which will appear on the film, shall be placed adjacent to the weld and their location accurately and permanently stamped near the weld on the outside surface of the drum or shell, so that a defect appearing on the radiograph may be accurately located in the actual weld.

The radiographs shall be submitted to the inspector. If the inspector requests, the following data shall be submitted with the radiographs: (1) the thickness of the base metal, (2) the distance of the film from the surface of the weld, (3) the distance of the film from the source of radiation.

The acceptability of welds examined by radiography shall be judged by comparing the radiographs with a standard set of radiographs, reproductions of which may be obtained by purchase from the Boiler Code Committee. In general the standards of judgment shall be:

(1b) Welds in which the radiographs show elongated slag inclusions or cavities shall be unacceptable if the length of any such imperfection is greater than $\frac{1}{3}T$, where T is the thickness of the weld. If the lengths of such imperfections are less than $\frac{1}{3}T$ and are separated from each other by at least $6L$ of acceptable weld metal, where L is the length of the longest imperfection, the weld shall be judged acceptable if the sum of the lengths of such imperfections is not more than T in a weld length of $12T$.

(2b) Welds in which the radiographs show any type of crack or zones of incomplete fusion shall be unacceptable.

(3b) Welds in which the radiographs show porosity shall be judged as acceptable or unacceptable by comparison with the standard set of radiographs.

(4b) A complete set of radiographs for each job shall be retained by the manufacturer and kept on file for a period of at least ten years.

j All vessels constructed under the requirements of this paragraph shall be stress relieved in accordance with Par. U-76.

k Vessels constructed in accordance with this paragraph shall be stamped "U-68" as required by Par. U-66.

l The manufacturer shall be responsible for the quality of the welding done by his organization and shall conduct tests of welding operators to determine their ability to produce welds of the required quality.

The manufacturerer shall satisfy the inspector that all the welding operators employed on a pressure vessel or pressure part of a unit have previously made test plates which comply with the requirements of the code. Such test plates shall have been made within a period of six months, except that when the welding operator is regularly employed on production work embracing the same process and type of welding the tests may be effective for one year.

It is the duty of the inspector to satisfy himself that only welding operators who are proved competent by these test plates are used to weld any pressure part and that all welding complies with the code requirements.

The inspector has the right at any time to call for and witness the making of test plates described in this paragraph by any welding operator and to observe the physical tests of them. For such qualification tests, the thickness of the test plate shall not be less than the approximate thickness of the plate or parts on which the welding operator is to work.

When more than one welding operator is employed on a pressure vessel, the required test plates for the individual vessels shall be made by the welding operator designated by the inspector.

The tests conducted by one manufacturer shall not qualify a welding operator to do work for any other manufaturer.

U-69 All vessels covered by this code when constructed in accordance with the rules of this paragraph may be used for any purpose except for containing lethal[1] gases or liquids and/or liquids operating at a temperature in excess of

[1]By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or vapor of the liquid mixed or unmixed with air when breathed is dangerous to life. For purposes of this code, this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel. Some such substances are hydrocyanic acid, carbonyl chloride, cyanogen, mustard gas, and xylyl bromide For the purposes of this code ammonia, chlorine, natural or manufactured gas, propane, or butane are not considered as lethal substances, but it is the intention of the Committee that their storage should not be permitted in pressure vessels built in accordance with Par. U-70.

300 F., provided the plate thickness of shells and of heads fabricated of more than one piece does not exceed 1½ in., unless the flange of such heads is reduced to not more than 1½ in. at the joint, and the maximum pressure does not exceed 400 lb. per sq. in., nor at a temperature in excess of 700 F. The limitation of plate thickness does not apply to heads formed of a single plate. This pressure limitation does not apply to vessels operated under hydraulic pressure at atmospheric temperature.

The joint efficiency E to be used in applying the rules in Par. U-20 shall be taken as 80 per cent.

Welding shall meet the following test requirements based on the qualification test procedure given in Pars. UA-30 to UA-46.

a Each manufacturer or contractor shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding process to determine its suitability to insure welds which will meet the required tests, but also of the welding operators to determine their ability to properly apply the procedure.

The tests of a welding operator shall be effective for a period of six months only, at the end of which time a repetition of the tests shall be made by the manufacturer. Exception to this is allowable when the welding operator is regularly employed on production work embracing the same process and type of welding, in which case the tests may be effective for a period of one year. The tests conducted by one manufacturer shall not qualify a welding operator to do work for any other manufacturer.

Each welding operator shall be assigned by the manufacturer an identifying number, letter, or symbol, which shall be stamped on all vessels adjacent to and at intervals of not more than 3 ft. along the welds which he makes either by hand or by machine, or a permanent record may be kept by the manufacturer of the welding operators employed on each joint, which shall be available to the inspector, and in such case the stamping may be omitted.

The manufacturer shall maintain a permanent record of the welding operators employed by him, showing the date and result of the tests and the identification mark assigned to each. These records shall be certified to by the manufacturer and accessible to the inspector. An authorized inspector shall have the right at any time to call for and witness tests of the welding process or of the ability of any welding operator.

b Test Welds. For the qualifications of a welding process, the number, type, and size of test welds shall comply with Par. UA-34.

For the testing of a welding operator, the number, type, and size of test welds shall comply with Par. UA-42.

c Test Specimens. For the qualification of a welding process, the number, type, and preparation of test specimens shall comply with Par. UA-36.

For the testing of a welding operator the number, type, and preparation of test specimens shall comply with Par. UA-44.

d Test Results. The minimum requirements for test results in the qualification of a welding process are as follows:

Tensile Strength. For the reduced-section tension-test specimens the tensile strength shall be not less than 95 per cent of the minimum of the specified tensile range of the plate used for double-welded butt joints, or 85 per cent for single-welded butt joints. (The tension test of the joint specimen as specified herein is intended as a test of the welded joint and not of the plate.)

Free-Bend Ductility. The ductility as determined by the free-bend-test method shall be not less than 20 per cent.

Soundness. The root-break, side-break, and nick-break tests of the weld shall show in the fractured surface complete penetration through the entire thickness of the weld, absence of oxide or slag inclusions, and a degree of porosity not to exceed six gas pockets per square inch of the total area of the weld surface exposed in the fracture, the maximum dimension of any such pocket not to be in excess of 1/16 in., or provided the total area of the gas pockets per square inch does not exceed the area of six gas pockets each 1/16 in. in diameter.

X-ray tests of the test plates as provided for in Par. U-68*i* may be substituted for the nick-break test.

The minimum requirements for test results in the testing of a welding operator are the same as above specified for soundness.

U-70 All vessels covered by this code, when constructed in accordance with the rules of this paragraph, may be used for the storage of gases or liquids, except lethal[1] gases or liquids, at temperatures not materially exceeding their boiling temperature at atmospheric pressure, and at pressures not to exceed 200 lb. per sq. in., and/or not to exceed a temperature of 250 F. The plate thickness of shells and of heads fabricated of more than one piece shall be limited to 5/8 in. The limitation of plate thickness does not apply to heads formed of a single plate. The maximum allowable working pressure of the vessel shall be calculated on the basis of a maximum unit joint working stress $(S \times E)$ in lb. per sq. in. as follows:

Double-welded butt joints for all joints	8,000
Single-welded butt joints for girth or head joints	6,500
Double full-fillet lap welds for girth joints only	7,000
Plug or intermittent welds for girth or head joints	5,600

For single-welded butt joints and for double full-fillet welds for longitudinal joints, the maximum unit joint working stress $(S \times E)$ shall be as follows: For material of thickness of less than 1/4 in., 5,600 lb. per sq. in.; for material of thickness of 1/4 to 3/8 in., 7,000 lb. per sq. in.

Lap joints as provided for in Par. U-73*a* shall not be used in the construction of vessels for the storage of gases of any kind at pressures in excess of 100 lb. per sq. in., nor for the storage of any liquid at a temperature exceeding its boiling point at atmospheric pressure.

Welding shall meet the following test requirements based on the qualification test procedure given in Pars. UA-30 to UA-46.

a Each manufacturer or contractor shall be responsible for the quality of the welding done by his organization and shall conduct tests not only of the welding process to determine its suitability to insure welds which will meet the required tests, but also of the welding operators to determine their ability to properly apply the procedure.

The tests of a welding operator shall be effective for a period of six months only, at the end of which time a repetition of the tests shall be made by the manufacturer. Exception to this is allowable when the welding operator is regularly employed on production work embracing the same process and type of welding, in which case the tests may be effective for a period of one year. The tests conducted by one manufacturer shall not qualify a welding operator to do work for any other manufacturer.

Each welding operator shall be assigned by the manufacturer an identifying number, letter, or symbol, which shall be stamped on all vessels adjacent to and at

[1]By "lethal substances" are meant poisonous gases or liquids of such a nature that a very small amount of the gas or vapor of the liquid mixed or unmixed with air when breathed is dangerous to life. For purposes of this code, this class includes substances of this nature which are stored under pressure or may generate a pressure if stored in a closed vessel. Some such substances are hydrocyanic acid, carbonyl chloride, cyanogen, mustard gas, and xylyl bromide. For the purposes of this code ammonia, chlorine, natural or manufactured gas, propane, or butane are not considered as lethal substances, but it is the intention of the Committee that their storage should not be permitted in pressure vessels built in accordance with Par. U-70.

intervals of not more than 3 ft. along the welds which he makes either by hand or by machine, or a permanent record may be kept by the manufacturer of the welding operators employed on each joint, which shall be available to the inspector, and in such case the stamping may be omitted.

The manufacturer shall maintain a permanent record of the welding operators employed by him, showing the date and result of the tests and the identification mark assigned to each. These records shall be certified to by the manufacturer and accessible to the inspector. An authorized inspector shall have the right at any time to call for and witness tests of the welding process or of the ability of any welding operator.

b Test Welds. For the qualification of a welding process, the number, type, and size of test welds shall comply with Par. UA-34.

For the testing of a welding operator, the number, type, and size of test welds shall comply with Par. UA-42.

c Test Specimens. For the qualification of a welding process, the number, type, and preparation of test specimens shall comply with Par. UA-36.

For the testing of a welding operator, the number, type, and preparation of test specimens shall comply with Par. UA-44.

d Test Results. The minimum requirements for test results in the qualification of a welding process are as follows:

Tensile Strength. For the reduced-section tension-test specimen the tensile strength shall be not less than 85 per cent of the minimum of the specified tensile range of the plate used. In no case shall the tensile strength be less than 42,000 lb. per sq. in. (The tension test of the joint specimen as specified herein is intended as a test of the welded joint and not of the plate.)

Free-Bend Ductility. The ductility as determined by the free-bend-test method shall be not less than 10 per cent.

Soundness. The root-break, side-break, and nick-break tests of the weld shall show in the fractured surface complete penetration through the entire thickness of the weld, absence of oxide or slag inclusions, and a degree of porosity not to exceed six gas pockets per square inch of the total area of the weld surface exposed in the fracture, the maximum dimension of any such pocket not to be in excess of 1/16 in., or provided the total area of the gas pockets per square inch does not exceed the area of six gas pockets each 1/16 in. in diameter.

Radiographic tests of the test plates as provided for in Par. U-68*i* may be substituted for the nick-break test.

The minimum requirements for test results in the testing of a welding operator are the same as above specified for soundness.

U-71 *Material. a* The materials used in the fabrication of any fusion-welded part of a pressure vessel covered by this code shall conform to Specifications S-1 for Steel Boiler Plate, S-2 for Steel Plates of Flange and Firebox Qualities for Forge Welding, S-4 for Seamless Steel Drum Forgings, S-25 for Open-Hearth Iron Plates for Flange Quality, S-26 for High Tensile Strength Carbon-Steel Plates for Pressure Vessels (Plates 2 in. and Under in Thickness), S-27 for High Tensile Strength Carbon-Steel Plates for Fusion-Welded Pressure Vessels (Plates Over 2 in. Up to and Including 4 in. in Thickness) or S-43 for Low-Carbon-Nickel Steel Plates for Boilers and Other Pressure Vessels. Shells fabricated from pipe shall conform to Specifications S-18 for Welded and Seamless Steel Pipe S-17 for Lap-Welded and Seamless Steel and Lap-Welded Iron Boiler Tubes, S-40 for Seamless Steel Boiler Tubes for High-Pressure Service, S-48 for Seamless Carbon-Molybdenum Alloy-Steel Boiler and Superheater Tubes or S-49 for Medium-Carbon Seamless Steel Boiler and Superheater Tubes. The carbon content in all such material shall not exceed 0.35 per cent.

b Material for manhole frames, nozzles and other pressure connections which are to be joined to the shell or heads by fusion welding shall, when forged, rolled, or cast, comply with the specifications given for forgings, plates, or castings, respectively, as to chemical and physical properties and be of good weldable quality. Small parts of cast, rolled, or forged steel of good weldable quality may be used as provided for in Par. U-12c.

c If, in the development of the art of welding, other materials than those herein described become available, specifications may be submitted for consideration.

U-72 *Preparation for Welding.* *a* The plates may be cut to size and shape by machining or shearing, or by flame cutting if the carbon content does not exceed 0.35 per cent. If shaped by flame cutting, the edges must be uniform and smooth and must be freed of all loose scale and slag accumulations before welding. The discoloration which may remain on the flame-cut surface is not considered to be detrimental oxidation. The plates or sheets to be joined shall be accurately cut to size and formed. In all cases the forming shall be done by pressure and not by blows, including the edges of the plates forming longitudinal joints of cylindrical vessels.

b Particular care should be taken in the layout of joints in which fillet welds are to be used so as to make possible the fusion of the weld metal at the bottom of the fillet. Great care must also be exercised in the deposition of the weld metal so as to secure satisfactory penetration.

c If the thickness of the flange of a head to be attached to a cylindrical shell by a butt joint exceeds the shell thickness by more than 25 per cent (maximum 1/4 in.), the flange thickness shall be reduced at the abutting edges either on the inside or the outside, or both, as shown in Fig. 176-a.

d The edges of the plates at the joints shall not have an offset from each other at any point in excess of one-quarter of the thickness of the plate, except for plates in excess of 3/4 in. in thickness, in which the offset shall not be more than 10 per cent (maximum 1/8 in.) for longitudinal joints, or 25 per cent (maximum 1/4 in.) for girth joints.

e In all cases where plates of unequal thicknesses are abutted, the edge of the thicker plate shall be reduced in some manner so that it is approximately the same thickness as the other plate.

f The design of welded vessels shall be such that bending stresses are not brought directly upon the welded joint. Fillet-welded corner joints shall not be used unless the plates forming the corner are properly supported independently of such welds.

g Bars, jacks, clamps or other appropriate tools may be used to hold the edges to be welded in line. The edges of butt joints shall be so held that they will not overlap during welding. Where fillet welds are used, the lapped plates shall fit closely and be kept together during welding.

h The surfaces of the sheets or plates to be welded shall be cleaned thoroughly of all scale, rust, oil, or grease for a distance of not less than 1/2 in. from the welding edge. Grease or oil may be removed with gasoline, lye, or the equivalent. A steel-wire scratch brush may be used for removing light rust or scale, but for heavy scale, slag, and the like, a grinder, chisel, air hammer, or other suitable tool shall be used to obtain clean and bright metal. When it is necessary to deposit metal over a previously welded surface, any scale or slag therefrom shall be removed by a roughing tool, a chisel, an air chipping hammer, or other suitable means to prevent inclusion of impurities in the weld metal.

i The dimensions and shape of the edges to be joined shall be such as to allow thorough fusion and complete penetration.

j For double-welded butt joints the reverse sides shall be chipped, ground, or melted out so as to secure a clean surface of the originally deposited weld prior to the application of the first bead of welding on the second side. Such chipping, grinding, or melting out shall be done in a manner that will insure proper fusion of the weld metal. These requirements are not intended to apply to any process of welding by which proper fusion and penetration are otherwise obtained and no impurities remain at the base of the weld.

k If the welding is stopped for any reason, extra care shall be taken in re-starting to get full penetration to the bottom of the joint and thorough fusion between the weld metal and the plates, and to the weld metal previously deposited.

l Where single-welded butt joints are used, particular care shall be taken in aligning and separating the edges to be joined so that complete penetration and fusion at the bottom of the joint will be assured.

U-73 *Joints.* *a Longitudinal.* Longitudinal joints on vessels covered by Pars. U-68 and U-69 shall be of the double-welded butt type and shall be reinforced at the center of the weld on each side of the plate by at least 1/16 in. up to and including 5/8-in. plate, and up to 1/8 in. for heavier plates. The reinforcement may be removed but if not removed shall be built up uniformly from the

surface of the plate to a maximum at the center of the weld. Particular attention is called, however, to the importance of the provision that there shall be no valley or groove along the edge of or in the center of the weld, but that the deposited metal must be fused smoothly and uniformly into the plate surface at the top of the joint.[1] The finish of the welded joint shall be reasonably smooth and free from irregularities, grooves, or depressions. Where a welded butt joint is made the equivalent of a double-welded butt joint (See note in Par. U-67), by using a backing-up strip and adding filler metal from one side only, the reinforcement shall not be less than 1/16 in. This type of joint shall only be used in cases where the inside of the weld is inaccessible for welding. The reinforcement may be machined off, if so desired.

The longitudinal joints of vessels covered by Par. U-70 may be of the butt-welded type for thicknesses of 5/8 in. or less, or of the double-welded lap type for thicknesses of 3/8 in. or less, or of the single-welded butt type for thicknesses of 1/4 in. or less. If of the lap type the throat dimension of each of the welds shall not be less than 5/8*T*, where *T* represents the thickness of the plate. Both edges of the lap shall be welded and the surface overlap shall not be less than 4*T*. The reinforcement for a single-welded butt joint shall not be less than 1/16 in. The reinforcement may be machined off, if so desired.

b Where vessels are made up of two or more courses with welded longitudinal joints, the joints of adjacent courses shall be not less than 60 deg. apart.

c *Circumferential.* Circumferential and other joints of vessels uniting the plates of the shell, or other pressure parts, except as provided for in Par. U-59, covered by Par. U-68 shall be of the double-welded butt type. Circumferential and other joints of vessels uniting the plates of the shell, or other pressure parts, except as provided for in Par. U-59, covered by Par. U-69 shall be of the double-welded butt type, except for thicknesses of 5/8 in. or less, in which case they may be of the single-welded butt type. Circumferential and other joints of vessels uniting the plates of the shell, or other pressure parts, except as provided for in Par. U-59, covered by Par. U-70 may be of the butt or lap type. The details of all of these joints shall conform to the requirements of longitudinal joints given in *(a)*.

d Dished heads concave to the pressure when used on vessels covered by Par. U-70 may be inserted with a driving fit and fillet welded inside and outside, except that for vessels 20 in. in diameter or less the heads may be welded on the outside only. The welds shall be located on the flange of the head at a distance not less than twice the thickness of the head from the point of tangency of the knuckle and not less than 1/2 in.

e Heads concave to the pressure and/or plate edges at girth joints to be attached by butt joints shall be aligned so that the deviations are not more than permitted by the limitations of Par. U-72, but if greater, correction shall be made by re-forming the shell or head, whichever is out of true, until the errors are within the limits specified. The edges of head and girth joints shall be kept separated at the point of welding enough to insure thorough penetration of the weld metal.

f Flat heads may be welded into any pressure vessel under the rules given in Par. U-39*a*.

U-74 *Holes.* No unreinforced hole shall be located in a welded joint. When an unreinforced hole in the plate is located near a welded joint the minimum distance between the edge of a hole and the edge of the weld shall be equal to the thickness of the plate when the plate thickness is from 1 in. to 2 in. With plates less than 1 in. in thickness, this minimum distance shall be 1 in. With plates over 2 in. in thickness, the minimum distance shall be 2 in.

U-75 *Dished Heads.* Dished heads convex to the pressure shall have a flange not less than 1 1/2 in. long and shall be inserted into the shell with a driving fit and welded as shown in Fig. U-14.

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[1]If the reinforcement is built up so as to form a ridge with a valley or depression at the edge of the weld next to the plate, the result is a notch which causes concentration of stress and reduces the strength of the joint.

Dished heads concave to the pressure shall have a length of flange not less than 1 in. for shells not over 24 in. in diameter. For vessels over 24 in. in diameter this length shall be not less than $1\frac{1}{2}$ in.

U-76 *Stress Relieving.* *a* All fusion-welded vessels constructed in accordance with Par. U-68 shall be stress relieved.

b Vessels constructed in accordance with Par. U-69 shall be stress relieved where the thickness exceeds $1\frac{1}{4}$ in., or where both the wall thickness is greater than 0.58 in. and the shell diameter less than 20 in., and for other wall thicknesses and shell diameters where the diameter in inches is less than $120t - 50$, where t is the thickness in inches.

c Where stress relieving is required it shall be done by heating uniformly to at least 1100 F, and up to 1200 F, or higher, if this can be done without distortion. The structure or parts of the structure shall be brought slowly up to the specified temperature and held at that temperature for a period of time proportioned on the basis of at least one hour per inch of thickness and shall be allowed to cool slowly in a still atmosphere.

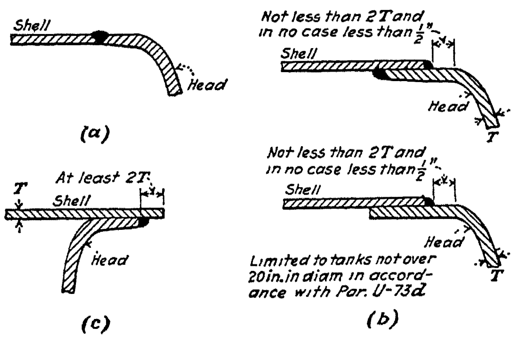


Fig. 176. Welded head attachments.

d All connections attached by fusion welding shall be stress relieved on vessels requiring stress relief and as required by Par. U-59*p* or *q*.

e The structure shall be stress relieved by any of the following methods:

(1) Heating the complete vessel as a unit.

(2) Heating a complete section of the vessel (head or course) containing the part or parts to be stress relieved before attachment to other sections of the vessel.

(3) In cases where the vessel is stress relieved in sections, stress relieving the final girth joints by heating uniformly a circumferential band having a minimum width of 6 times the plate thickness on each side of the welded seam in such a manner that the entire band shall be brought up to the temperature and held for the time specified above for stress relieving.

(4) Nozzles or welded attachments for which stress relief is required, may be locally stress relieved by heating a circular area around the nozzle or attachment provided any part of the welded edge thereof is not less than $12t$ (t = thickness of plate) from the nearest adjacent welded joint or other element that would tend to restrict the free expansive movement of the heated area. The outside dimensions of this annular ring to be heated shall be at least $6t$ away from the outermost weld but not less than 5 in., and the entire area shall be heated simultaneously.

Rules for Qualification of Welding Process and Testing of Welding Operators

Part I *Qualification for Welding Process*

UA-30 *Limitation of Variables.* For the qualification of each welding process the manufacturer shall establish and record as a process specification the definite limits of all essential variables involved, and in the investigation of each

welding process the process specification shall be followed. The process specifications shall cover the following items: Process, base metal, filler metal, preparation of base material, nature of welding flame, nature of electric current and

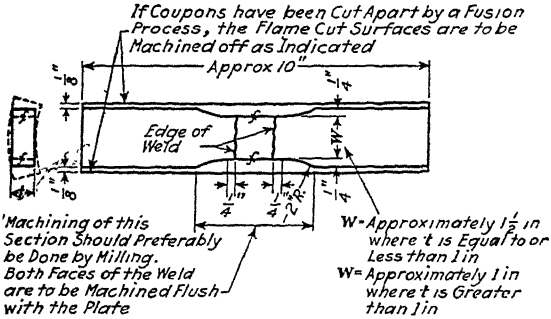


Fig. 177. Reduced-section tension-test specimen.

current characteristics, method of welding, number of layers or beads, shielding of arc or flame, cleaning or peening, removal of defects, treatment of underside of groove, heat treatment.

UA-31 *Types of Test and Purpose.* The types of tests outlined below are to determine the tensile strength, ductility, and lack of soundness of welded joints made under a given process specification. Whereas some of the required tests are intended solely for the determination of lack of soundness, all types of test specimens shall be examined for lack of soundness if failure occurs in the welded joint Lack of fusion or root penetration, cracks, slag, and gas inclusions constitute lack of soundness The tests required are as follows:

For all types of welded butt joints.

(1) Reduced-section tension test: For tensile strength and lack of soundness of welded joints.

(2) Free-bend test: For ductility of weld metal in welded joints and lack of soundness.

(3) Root-break test: For lack of soundness of welded joints.

(4) Side-break test: For lack of soundness of welded joints.

(5) Nick-break test: For lack of soundness of weld metal in welded joints.

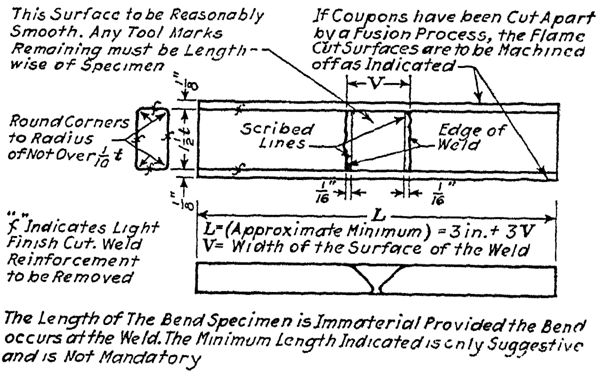


Fig. 178. Free-bend-test specimen

UA-32 *Base Material and Its Preparation.* The base material and its preparation for welding shall comply with the process specification. For all types of welded joints the length of the weld and the dimensions of the base material shall be such as to provide sufficient material for the test specimens called for hereinafter.

UA-33 *Position of Test Welds. a Classification of Position.* All welds that will be encountered in actual construction shall be classified as being in the (1) flat, (2) horizontal, (3) vertical, or (4) overhead position depending upon the manner in which the weld metal must be deposited.

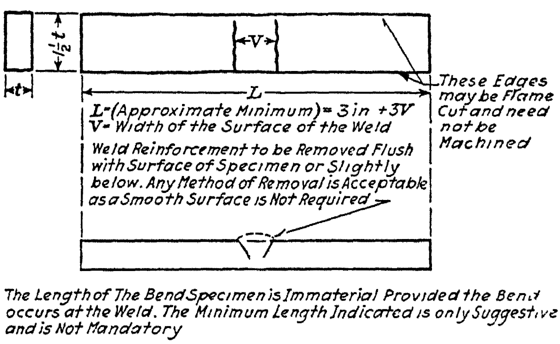
b Butt Joints in Plate. In making the test welds for butt joints in plate, the test plates shall be placed in an approximately horizontal plane for the (1) flat and (4) overhead positions, and in an approximately vertical plane for the (2) horizontal and (3) vertical positions. The weld metal shall be deposited from the upper side of the test plates for the flat position, and from the underside thereof for the overhead position. The test welds shall be run horizontally for the horizontal position and vertically for the vertical position.

UA-34 *Number, Type, and Size of Test Welds. Butt Joints in Plate.* For butt joints in plate two test welds shall be made for each process and position to be used in construction. One test weld shall be made in the minimum thickness and one in the maximum thickness of material that will be used in construction except that the thickness shall not exceed that permitted for the particular class of vessels under construction, that is, Par. U-69 or Par. U-70 vessels.

Lap Joints in Plate for Par. U-70 Vessels. If lap joints are to be used in the construction of Par. U-70 vessels, two single-welded butt joints shall be made for each process and position to be used in construction. One test weld shall be made in a plate thickness equal to the maximum size single-pass fillet weld and one in the plate thickness equal to the minimum size multiple-pass fillet weld that will be used in construction, except that in no case may the plate thickness for such test welds exceed 3/8 in.

UA-35 *Welding Procedure.* The welding procedure shall comply in all respects with the process specification established by the manufacturer.

UA-36 *Test Specimens—Number, Type, and Preparation. Butt Welded Joints.* From each test weld there shall be taken the following test specimens



The Length of The Bend Specimen is Immaterial Provided the Bend occurs at the Weld. The Minimum Length Indicated is only Suggestive and is Not Mandatory

Fig. 179. Root-break-test specimen.

which shall be prepared for testing as shown in the figures referred to:

For single-welded butt joints in plate: Two reduced-section tensile specimens, Fig. 177; two free-bend specimens, Fig. 178; two root-break specimens, Fig. 179; two side-break specimens, Fig. 180; two nick-break specimens, Fig. 181.

For double-welded butt joints in plate: Two reduced-section tensile specimens, Fig. 177; four free-bend specimens, Fig. 178; two side-break specimens, Fig. 180; two nick-break specimens, Fig. 181.

UA-37 *Method of Testing Specimens. a Reduced-Section Tensile Speci-*

mens. Before testing, the width, thickness and cross-sectional area at the weld shall be recorded. Each specimen shall be loaded in tension at a uniform rate until fracture occurs, and the maximum load in pounds shall be recorded. The tensile strength shall be recorded as the maximum load divided by the cross-sectional area as above recorded. If failure occurs in the welded joint, the fractured surfaces shall be examined for lack of soundness.

b Free-Bend-Test Specimens. For single-welded butt joints the scribed lines shown in Fig. 178 shall be on the surface opposite the root of the weld. For double-welded butt joints the scribed lines on two of the specimens shall be on one surface of the weld and on the other two specimens shall be on the opposite surface of the weld. The distance between the scribed lines is to be measured in 1/100 parts of an inch and this measurement recorded as the initial gage length.

Initial bends shall be made as shown by the broken lines in Fig. 182 and in all cases the initial bends shall be in the same relation to the scribed lines as shown in Fig. 182.

The specimen with the initial bend at each end shall be placed as a strut in a vise or compression machine and pressure applied gradually (that is, without shock) at the ends until failure occurs in the outside fibers of the bend specimen. When a crack is observed in the convex surface of the specimen between the edges, the specimen shall be considered to have failed and the test shall be stopped. Cracks at the corners of the specimens shall not be considered as a failure. The

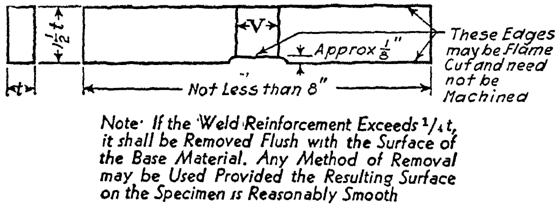


Fig. 180. Side-break-test specimen.

appearance of small defects in the convex surface shall not be considered as a failure if the greatest dimension does not exceed 1/16 in. The specimen shall then be removed from the vise or machine and the maximum distance between the scribed lines measured on the curved surface in 1/100 parts of an inch, this measurement being recorded as the final gage length. This measurement may be made by means of a flexible scale. The difference between the final and initial gage lengths divided by the initial gage length shall be recorded as the percentage of "free-bend ductility." The specimen shall then be replaced in the vise or compression machine and pressure again applied until the specimen is broken in two or until it is bent flat upon itself. If the specimen breaks in the welded joint the surface of the fracture shall be examined for lack of soundness.

c Root-Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 183. The root of the weld shall be opposite the side upon which pressure is applied. If fracture of the specimen does not occur using the method shown in Fig. 183, the specimen shall be removed from the fixture

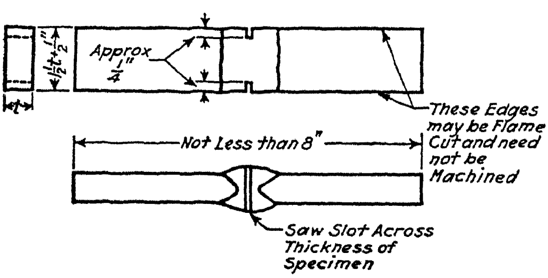


Fig. 181. Nick-break-test specimen.

shown and pressure shall then be applied to the specimen in the direction of *AA* until fracture occurs or the specimen is bent flat upon itself. The surface of the fracture shall be examined for lack of soundness.

d Side-Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 184. If fracture of the specimen does not occur using the method shown in Fig. 184, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction *AA* until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of fusion.

e Nick-Break Specimens. The specimen shall be supported as shown in Fig. 185 and broken by a sudden blow or blows applied at the center of the weld. The blow should be applied preferably by a power hammer or falling weight, and be of sufficient intensity to cause a sharp sudden fracture of the specimen through the nicked portion. The surfaces of the fracture shall be examined for lack of soundness.

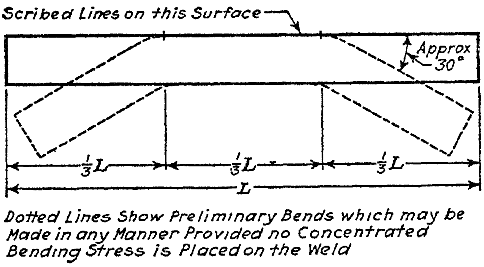


Fig. 182. Position of initial bends in free-bend-test specimen.

Part II *Qualification Tests of Welding Operators*

UA-38 For the qualification of an operator under any welding process that has been qualified as outlined in Part I, the following procedure shall be used.

UA-39 *Types of Test Required.* The tests required for the qualification of an operator are limited to those intended for determination of lack of soundness. For each process an operator need be qualified only for the types of joints and positions that he will encounter in construction. The types of tests required are as follows:

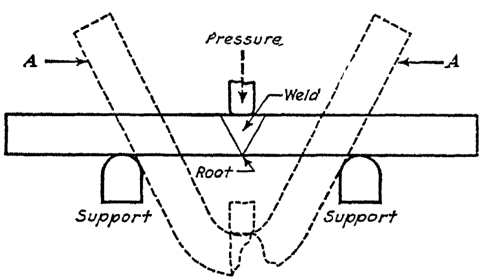


Fig. 183. Method of testing root-break-test specimen.

(1) Single-welded butt joints: *(a)* Face-break test, *(b)* Root-break test, *(c)* Side-break test.

(2) Double-welded butt joints: *(a)* Face-break test, *(b)* Side-break test.

UA-40 *Base Material and Its Preparation.* The base material and its preparation for welding shall comply with the process specification. For all types of welded joints the length of the weld and the dimensions of the base material shall

be such as to provide sufficient material for the test specimens called for hereinafter.

UA-41 *Position of Test Welds. a Classification of Position.* The classification of position shall be the same as specified in Par. UA-33*a*, namely, (1) flat, (2) horizontal, (3) vertical, (4) overhead.

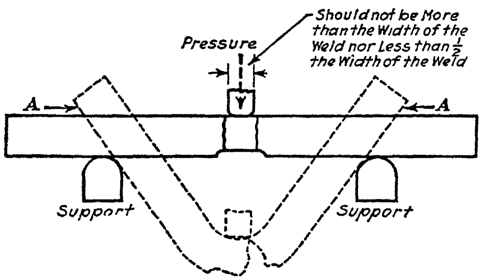


Fig. 184. Methods of testing side-break-test specimen.

b Butt Joints in Plate. In making the test welds for butt joints in plate, the test plates shall be placed in an approximately horizontal plane for the (1) flat and (4) overhead positions, and in an approximately vertical plane for the (2) horizontal and (3) vertical positions. The weld metal shall be deposited from the upper side of the test plates for the (1) flat position, and from the underside thereof for the (4) overhead position. The test welds shall be run horizontally for the (2) horizontal position and vertically for the (3) vertical position.

UA-42 *Number, Type and Size of Test Welds. Butt Joints in Plate.* For butt joints in plate the operator shall make for each process and position one test weld in the maximum thickness of material for which he is to be qualified except that the thickness shall not exceed that permitted for the particular class of vessels under construction, that is, Par. U-69 or Par. U-70 vessels.

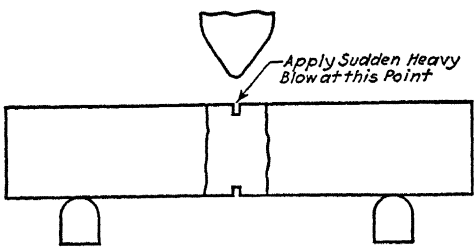


Fig. 185. Method of testing nick-break-test specimen.

UA-43 *Welding Procedure.* The welding procedure shall comply in all respects with the process specification.

UA-44 *Test Specimens, Number, Type, and Preparation.—Butt Welded Joints.* From each test weld there shall be taken the following test specimens which shall be prepared for testing as shown in the figures referred to:

For single-welded butt joints in plate: One face-break specimen, Fig. 179; one root-break specimen, Fig. 179; one side-break specimen, Fig. 180.

For double-welded butt joints in plate: Two face-break specimens, Fig. 186; one side-break specimen, Fig. 180.

UA-45 *Method of Testing Specimens. a Face-Break-Test Specimens.* The specimen shall be supported and pressure applied as shown in Fig. 183, except that the face of the weld shall be opposite the side upon which pressure is applied. For double-welded butt joints one specimen shall be tested with one face down and the other specimen with the opposite face down.

If fracture of the specimen does not occur using the method shown in Fig. 183, the specimen shall be removed from the fixture and pressure shall then be applied to the specimen in the direction AA until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of soundness.

b Root-Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 183. The root of the weld shall be opposite the side upon which pressure is applied. If fracture of the specimen does not occur using the method shown in Fig. 183, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction AA until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of soundness.

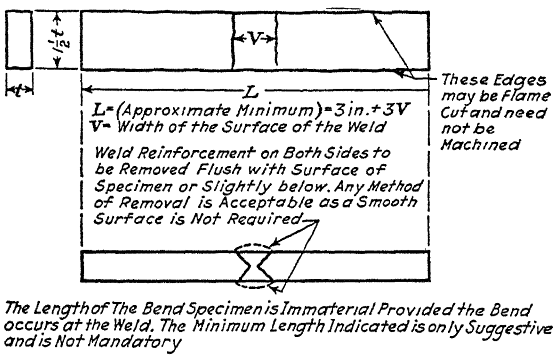


Fig. 186. Face-break-test specimen.

c Side-Break Specimens. The specimen shall be supported and pressure applied as shown in Fig. 184. If fracture of the specimen does not occur using the method shown in Fig. 184, the specimen shall be removed from the fixture shown and pressure shall then be applied to the specimen in the direction AA until fracture occurs or the specimen is bent flat upon itself. The surfaces of the fracture shall be examined for lack of soundness.

UA-46 *Retests.* In case an operator fails to meet the requirements on one or more test welds a retest may be allowed under the following conditions:

(1) An immediate retest may be made which shall consist of two test welds of each type on which he failed, all of which shall meet all the requirements specified for such welds.

(2) A retest may be made after the lapse of one week provided there is evidence that the operator has had further training or practice. In this case only one set of test welds of each type on which he failed need be made.

WELD INSPECTION

From an inspection standpoint one of the greatest advantages of arc welding is that *the inside of the joint may be observed as the joint is being made.* Welding is probably the one process of joining metals where this is true. Inspection is best accomplished during the process of making the weld.

Each and every weld cannot be inspected, but as in many other processes the careful observation of a number of joints is used as a basis of inspection and report. Work of any description is seldom tested or inspected in all details. Obviously the proper type of generator, the correct electrodes and suitable base metal must be used.

Various methods may be employed in the inspection of welds, the simplest and most expedient being visual inspection. Experience and keen perception of the inspector are requisites. Visual inspection may be considered under these three groups:

(1) Training the inspector
(2) Inspection during welding
(3) Inspection after welding

Training the Inspector.—The method: Maintain all conditions except one fixed and note the effect of variation of that one condition. The conditions are: (1) arc current, (2) arc voltage, and (3) arc speed, for a certain plate thickness, type of joint, and size of electrode. The results to be observed are:

(1) Consumption of electrode. How it burns off—smoothly or evenly.
(2) Crater. Its size, shape and appearance of surface.
(3) Bead. Its size, shape and fusion.
(4) Sound of the arc.

Observing these four items and noting the effect of variation of one of the three conditions the initial observation is made under normal conditions, i.e.

(1) arc current = 100% normal
(2) arc voltage = 100% normal
(3) arc speed = 100% normal

The second observation is made with
(1) arc current = 50% normal
(2) arc voltage = 100% normal
(3) arc speed = 100% normal

The third observation is with
(1) arc current = 150-250% normal
(2) arc voltage = 100% normal
(3) arc speed = 100% normal

Fourth observation is with
(1) arc current = 100% normal
(2) arc voltage = 50% normal
(3) arc speed = 100% normal

Fifth observation is with
(1) arc current = 100% normal
(2) arc voltage = 150-200% normal
(3) arc speed = 100% normal

Sixth observation is with
(1) arc current = 100% normal
(2) arc voltage = 100% normal
(3) arc speed = 50% normal

Seventh observation is with
(1) arc current = 100% normal
(2) arc voltage = 100% normal
(3) arc speed = 50-250% normal

The effects of variation on conditions are more apparent when bare electrodes are used and it is suggested that these be used for the first series of observations. Then use the shielded arc electrodes which are more automatic and less sensitive to adverse conditions, assuring excellent results readily. The method of observation is the same as for bare electrodes.

Careful observation of the operations by *actual performance* in the shop will enable a good observer to become a trained welding inspector. This training and experience will be of great assistance to the inspector in judging welds both during and after welding.

Inspection During Welding.—The method outlined above applies to the inspection of welds during their making.

Inspection After Welding.—As in the inspection during welding, certain telltale signs will reveal considerable information to a qualified inspector after the welding is done. Items to consider in inspecting after welding include size and shape of bead, appearance of bead, undercut, overlap, location of craters, (indicating where operator

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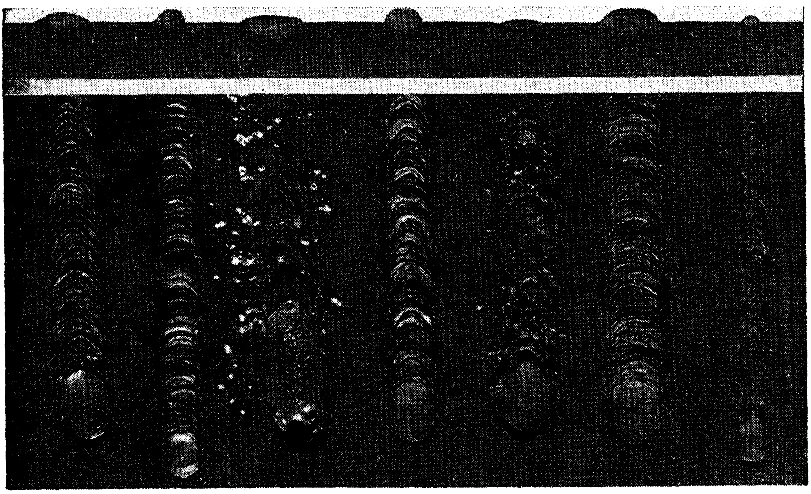


Fig. 187. Plan and elevation views of welds made with shielded arc electrode under various conditions. (A) Current, voltage and speed normal. (B) Current too low. (C) Current too high. (D) Voltage too low. (E) Voltage too high. (F) Speed too low. (G) Speed too high.

started and stopped welding). A study of the weld and proper interpretation of these telltale signs will disclose other conditions of welding. These conditions are illustrated in Figs. 187 and 188 for

Tabulation of Resultant Weld Characteristics obtained when proper welding procedure is used except as indicated. This tabulation applies only to welding of mild rolled steel in flat position with heavily coated shielded arc electrodes.

RESULTING WELD CHARACTERISTICS (See Fig. 188)

	"F"	"A"	"B"	"C"	"D"	"E"	"G"
Arc current	Normal	Low	High	Normal	Normal	Normal	Normal
Arc volts	Normal	Normal	Normal	Low	High	Normal	Normal
Arc speed	Normal	Normal	Normal	Normal	Normal	Low	High
Burn Off of Electrode	Normal appearance. Coating burns evenly	Practically same as preceding	Coating is consumed at irregular high rate — watch carefully	Coating too close to crater. Touches molten metal resulting in porosity	Drops at end of electrode flutter and then drop into crater	Normal	Normal
Penetration — Fusion (crater)	Fairly deep and well defined	Not very deep nor well defined	Deep, long crater	Small	Wide and rather deep	Crater normal	Small, rather well-defined crater
Appearance of Bead	Excellent fusion — no overlap	On top of plate. Not as much overlap as with bare rod.	Broad, thin bead — Good fusion	High bead not as pronounced as for low amps. Somewhat broader	Wide — Spattered	Wide bead— overlap large. Base metal and bead excessively heated.	Small bead — undercut — reduction in bead size and undercutting depends on speed and amps.
Arc Sound	Sputtering hiss plus sharp crackling	Irregular sputtering. Some crackling	Regular explosive sounds	Hiss plus steady sputter	Soft sound plus hiss and few crackles	Normal	Normal

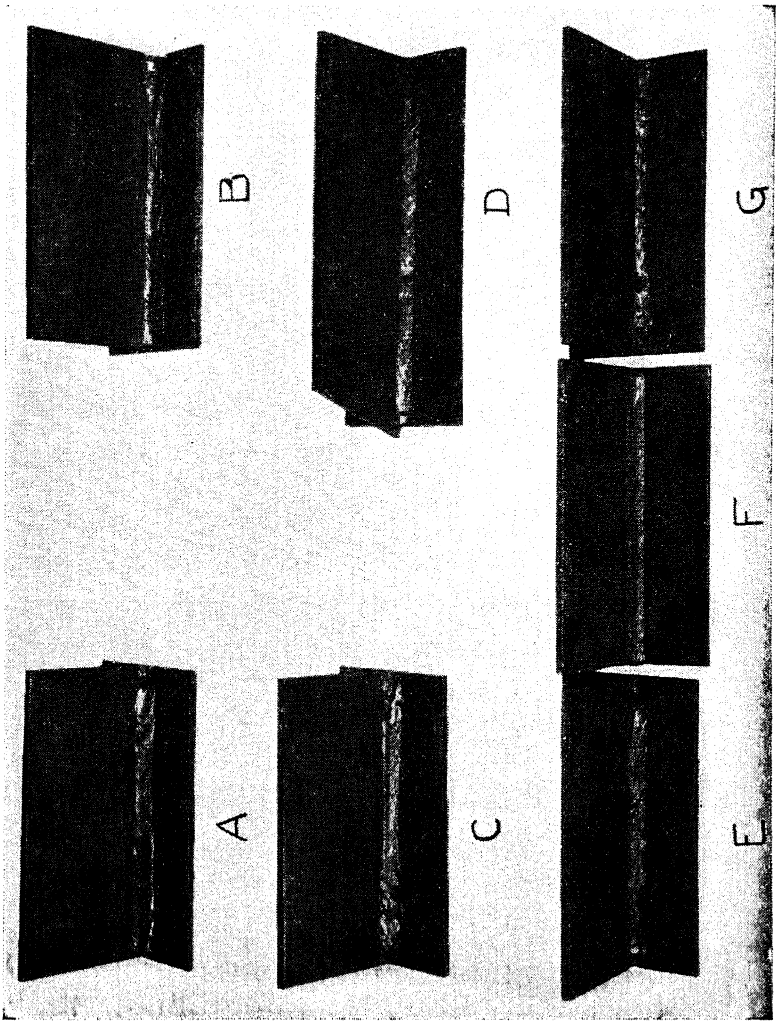


Fig. 188. Fillet weld specimens made with shielded arc electrode. See table on page 126 for explanation

shielded arc electrode and in Fig. 189 for bare electrode. The illustrations show the appearance of beads deposited under different procedures, some good—some poor. A study of these will indicate clearly what normal conditions are and the comparison to abnormal conditions. See the tables on Page 126 and 128.

Inspection with Stethoscope.—By listening with the stethoscope while tapping gently along a welded seam with a light hammer a very experienced person is able to detect the difference in sound when the hammer strikes the weld in the immediate vicinity of a fault. The stethoscope method requires by far the least and simplest equipment of any of the non-destructive inspection methods excepting visual

Tabulation of Resultant Weld Characteristics obtained when proper welding procedure is used except as indicated. This tabulation applies only to welding of mild rolled steel in flat position with bare or washed electrodes.

RESULTING WELD CHARACTERISTICS (See Fig. 189)

	"G"	"A"	"B"	"D"	"E"	"F"	"H"	(C)
Arc current	Normal	Low	High	Normal	Normal	Normal	Normal	Normal
Arc volts	Normal	Normal	Normal	Low	High	Normal	Normal	Normal
Arc speed	Normal	Normal	Normal	Normal	Normal	Low	High	
								Wrong Polarity
Burn Off of Electrode	Stable			Rod apt to freeze to work	Bubble on end of rod—arc wanders			
Penetration — Fusion (crater)	Good — crater averages $\frac{1}{16}''$ deep for $\frac{1}{8}''$ rod	Poor — very shallow crater	Poor weld characteristics — porosity	Poor — crater shallow	Very little fusion — crater shallow	Crater excessively deep	Almost no crater — no fusion	No crater — porosity
Appearance of Bead	Smooth, no overlaps	Bead piles up — overlap	Flat	High	Flat	Piles up and rolls over — bluish color	Irregular in width — flat	Irregular
Arc Sound	Steady, sharp crackling sound	Pulsating "low energy"	Explosions crackling	Steady sputter	Whistling or hissing and crackling			Sputter
Comments			Electrode becomes red hot — splatter — weld porous		Splatter — pockets in weld — weld oxidizes	Electrode becomes red at tip — splatter		Splatter

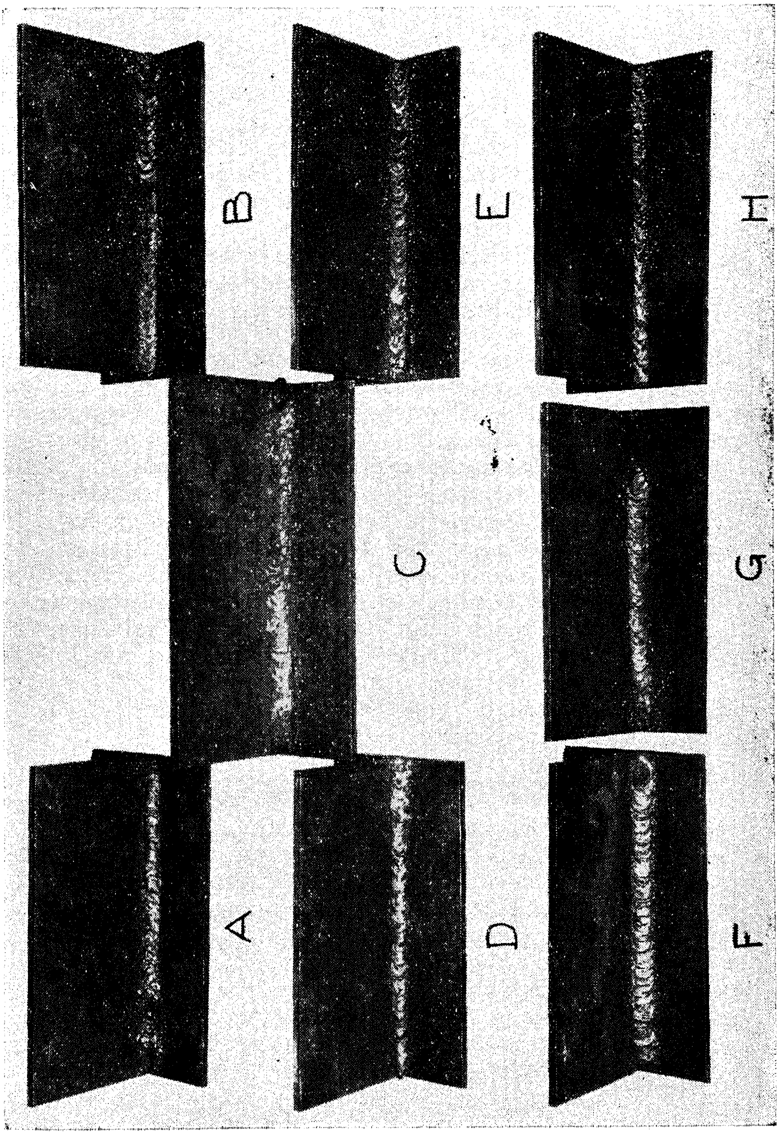


Fig. 189. Fillet weld specimens made with bare electrode. See table on page 128 for explanation.

inspection, described previously. Its effective use requires a high order of perception of sound quality, together with considerable skill and training.

Electro-Magnetic Method of Inspection.—The magnetic reluctance of a weld of ferro-magnetic material is increased by any fault occurring in it. Hence, if a magnetic flux is passed through the weld and adjacent base metal, with the lines of flux approximately at right angles to the

weld, there will be more leakage flux directly over the faults than at good portions of the weld. The faults can be detected either by sifting iron filings or iron powder on a piece of paper placed on the weld and observing the picture formed, or by exploring with an instrument capable of reading the strength of the leakage flux. An additional variation is to sift the powder direct on to the metal being tested. This gives greater sensitivity and reaches deeper into the weld being tested.

This method is quite sensitive to cracks or poor fusion at or only a short distance under the surface of the weld, particularly if the weld is smooth and flat and in flat position. The sensitivity is considerably impaired by the rough surface of the weld, by sloping or vertical surface, or by the fault being buried far beneath the surface.

Inspection by X-Ray.—Weld metals can be X-rayed and their internal defects made clearly visible on photographic film. If within a weld there are cracks, holes or general porosity, the X-ray film will reveal the condition. The method is simple. It consists of placing an X-ray tube on one side of the weld and the photographic film on the other. After proper exposure, depending upon the thickness of the material, strength of X-ray, the film is developed and examined for defects in the weld. This method is widely used as final inspection of pressure vessels which come under U-68 of the A.S.M.E. Boiler Code.

The Gamma Ray Method.—Newer than but similar in method to X-ray inspection is inspection by Gamma rays. The Gamma ray emanates from radium. This ray penetrates the weld more quickly than the X-ray and is therefore used for inspecting heavy work which would require impracticably long X-ray exposures or for speeding up inspection on ordinary material

INSURANCE OF FUSION WELDED VESSELS

Boiler insurance is that form of insurance protection which reimburses the policyholder against certain losses that he may suffer through the explosion or bursting of a steam boiler because of the pressure of steam within it. This form of insurance may also include many kinds of unfired pressure vessels, such as air tanks, water storage tanks, ammonia receivers, and a vast number of other types of vessels or tanks used in various industries. For many such vessels, freedom from leakage is essential and increasing use is being made of fusion welding, instead of riveting, in their fabrication. However, the welding must be properly done, so as to be free from serious defects and avoid any failure of the vessel which might occur and cause extensive property damage and possibly loss of life.

Just as fire insurance companies seek to prevent the cause of fires, so boiler insurance companies seek to overcome weaknesses in pressure vessel construction, and thus reduce both the frequency of, and the damage resulting from, the explosion of such vessels.

Boiler insurance companies for a long time regarded fusion welded vessels with suspicion because experience had shown that many such vessels were poorly welded. Because of the difficulty of judging the soundness of a welded joint from its exterior appearance, good welding suffered with the bad. One prominent boiler insurance company,

which felt that this condition should not exist, decided that the most satisfactory means of assuring that a fusion welded vessel was safe to operate would be to start in the plant of the manufacturer where the vessel is built. It was felt that safe welds would be obtained if (1) proper procedure of welding, one that would give proper tensile strength, ductility and soundness, was followed, and if (2) the welding operators were trained and then tested to determine their ability to produce sound welds under that procedure.

The fundamentals of this plan were later incorporated in the A.S.M.E. Codes for the Construction of both Boilers and Unfired Pressure Vessels. Boiler insurance companies have now adopted those Codes as the recommended standard of construction for all kinds of pressure vessels, both riveted and fusion welded.

The A.S.M E. Code does not specify how the welding must be done. It does require that the manufacturer, who wishes to stamp his products with the Code symbol, must definitely fix or limit all variables that are an essential part of his welding process. He must then prove, by certain tests, that all welding operators he employs on construction of Code vessels have demonstrated their ability, when following the fixed procedure of welding, to produce welds that will show the degree of tensile strength, ductility and soundness, called for by the Code.

The A.S.M.E. Code requires that a vessel which is to be stamped with the Code symbol shall be inspected during construction by an authorized inspector. The Code defines an authorized inspector as "A state or municipal inspector of pressure vessels, or an inspector employed regularly by an insurance company which is authorized to do a pressure vessel insurance business in the state in which the vessel is built, or in the state in which it is to be used, if known."

It is the practice of one Boiler Insurance Company, which is extensively engaged in making shop inspections of Code vessels, to require the manufacturer to furnish a written specification outlining in detail his procedure for welding. The Insurance Company then makes an investigation at the plant of the manufacturer to determine that the given procedure will produce the required results and the manufacturer is then required to test all his welding operators. Inspections are made by the Insurance Company Inspector during construction and at the time of hydrostatic test of all vessels. If all requirements of the A.S.M.E. Code have been met, the Inspector authorizes application of the Code stamping to each boiler or pressure vessel and signs the certificate stating that the object has been constructed in accordance with the Code. A somewhat similar procedure has been adopted for the investigation of fabricators of fusion welded pipe fittings and of fusion welded pipe lines.

It will be noted from the above that the Insurance Company, through its Inspectors, certifies that a specific boiler or pressure vessel complies with the A.S.M.E. Code and before such certification can be made it is necessary that the Inspector satisfy himself that the method of welding was satisfactory and that the welding operators were competent to apply that method. However, the Inspector does

not certify, qualify or approve any welding process, welding operators, welding electrodes or other equipment used in the fabrication of the vessel.

WELDING CODES, RULES, REGULATIONS AND SPECIFICATIONS

Codes recommending procedures for obtaining specified results in the welding of various structures have been established by societies, institutes, bureaus and associations, as well as state and federal departments. The principal codes are listed below according to applications. Following each code designation is a number which refers the reader to the name and address of the sponsor given at the end of the code listing. Copies of any particular code or codes may be obtained by writing the sponsor at the address given.

PRESSURE VESSELS

A.S.M.E. Power Boiler Code for welding drums and shells of power boilers. (1)

A.S.M.E. Unfired Pressure Vessel Code for welding all types of pressure vessels. See Page 106 (1)

A.P.I.-A.S.M.E. Unfired Pressure Code for welding tanks, etc. for petroleum, liquids and gases. (1) or (2)

Amended Rules I and II of the general rules and regulations of the U. S. Dept. of Commerce, Bureau of Navigation and Steamboat Inspection—51st supplement to general rules and regulations containing a section on fusion welding, (3) or (4) A.W.S. Rules and Fusion Welding of Drums and Shells of Marine Boilers and Pressure Vessels. (1)

Codes Used by Department of the U. S. Gov't including specifications of bureau of engineering, U. S. Navy, (14) Many codes confidential.

Requirements for Repairs by Fusion Welding of Boilers or Other Pressure Vessels—a brief set of rules formulated by the National Bureau of Casualty and Surety Underwriters in cooperation with the National Board of Boiler and Pressure Vessel Inspectors, to indicate the extent to which fusion welding will be acceptable to the authorities for repairing steam boilers. (5)

TANKS

A.W.S. Tentative Rules for the Fusion Welding of Gravity Tanks, Tank Risers and Towers. (6) or (10)

PIPING

Code for Pressure Piping: Power—Gas and Air—Oil—District Heating. (4) or (10)

Specifications of Heating and Piping Contractors National Association for Welding Steel and Wrought Iron Pipe. Contain requirements for fusion welding of all steel and wrought iron piping, both standard and extra heavy weight, plain or galvanized, for steam and process piping operating at pressures not exceeding 250 lb. gauge nor 406° F. (7)

Code and Regulations for the Welding of Steam Piping—de-

partment of labor and industry, board of boiler rules, State of Michigan. (8)
Revised Tentative Code of Safety Rules and Regulations Covering the Installation of Pressure Piping—department of industrial relations and the industrial commission of the State of Ohio. (9)
Code for Marine Piping. (10)

STRUCTURAL AND BRIDGES
A.W.S. Code for Fusion Welding and Gas Cutting in Building Construction. Includes appendices on specifications for filler metals, qualification tests for operators of welding equipment, recommended welding practices and weld symbols. (10) A.W.S. Code for Resistance Welding of Structural Steel in Building Construction. (10)
A.W.S. Specifications for Design, Construction, Alteration and Repair of Highway and Railway Bridges by Fusion Welding. (10)
Navy Department Code for yards and docks. (15)

MACHINERY
A.W.S. Code for Fusion Welding and Flame Cutting in Machinery Construction. (10)

SHIPS
A.W.S. Marine Code for Welding and Gas Cutting—Part D. Rules for the fusion welding of hulls and hull parts. (10)
Lloyd's Register of Shipping Regulations for the Application of Electric Welding in Ship Construction. Contained in this society's rules and regulations for the Construction of steel vessels. (11)
General Specifications—Bureau of Engineering, U. S. Navy. (12)
Rules of American Bureau of Shipping. (13)
Specifications for Electrodes, U. S. Navy. (14)
Marine Piping Code. (10)

AIRCRAFT CONSTRUCTION
Department of Commerce Specifications, bureau of air commerce. (14) Also confidential specifications, Air Corps, Department of War. (14)

GENERAL RULES
A.W.S. Tentative Specifications for Filler Metal for Use in Fusion Welding. (10)
A.W.S. Fusion Welding Symbols. (10)
A.W.S. Report of Committee on Welded Rail Joints. (10)
A.W.S. Rules for Welding or Cutting Certain Types of Containers Which Have Held Combustibles. (10)
Tentative Rules for Qualification of welding processes and testing of Welding Operators. (10)
Standard Methods for Mechanical Testing of Welds. (10)
Welding Symbols and Instructions for their use. (10)

ELECTRIC WELDING MACHINERY
A.S.A. Codes for Arc Welding Machines and Transformers and Resistance Welding Transformers. (4)

NAMES AND ADDRESSES OF CODE SPONSORS

(1) American Society of Mechanical Engineers, 29 W. 39th St., New York City. (2) American Petroleum Institute, 50 W. 50th St., New York City. (3) Government Printing Office, Washington, D. C. (4) American Standards Association, 33 W. 39th St., New York City. (5) National Bureau of Casualty & Surety Underwriters, 1 Park Ave., New York City. (6) National Board of Fire Underwriters, 85 John Street, New York City. (7) Heating, Piping and Air Conditioning Contractors, Suite 1401, 1250 Sixth Ave., New York City. (8) Department of Labor and Industry, Lansing, Mich. (9) Superintendent, Division of Safety and Hygiene, Columbus, Ohio. (10) American Welding Society, 33 W. 39th St., New York City. (11) Lloyd's Register of Shipping, 17 Battery Place, New York City. (12) Bureau of Engineering, United States Navy Dept., Washington, D. C. (13) American Bureau of Shipping, 24 Old Slip, New York City. (14) Bureau of Department mentioned, Washington, D. C. (15) United States Navy Department, Bureau of Docks and Yards, Washington, D. C.

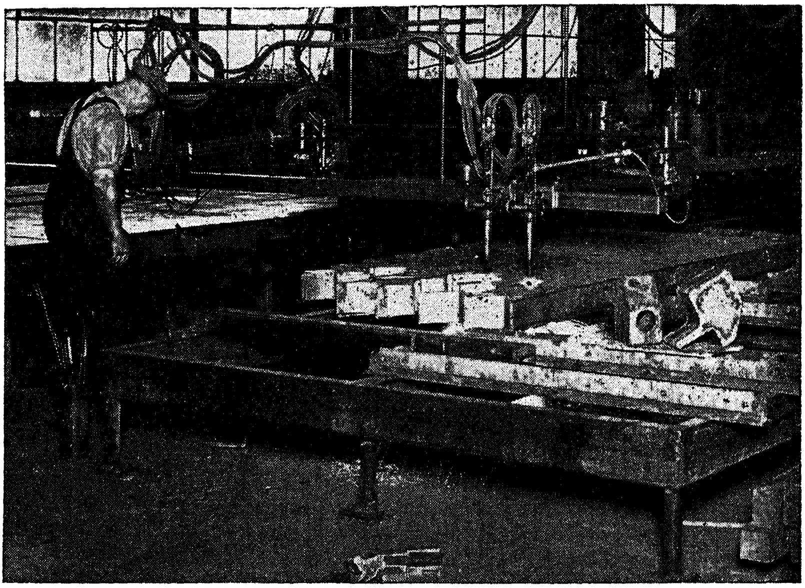


Fig. 190. A large "Travograph" cutting axle brackets from steel 7" thick.

FLAME-CUTTING

Description.—Flame-cutting of ferrous metals is a process of preheating the material to be cut to its kindling or ignition temperature, and then rapidly oxidizing it by means of a closely controlled and regulated jet or stream of oxygen issuing from a special tool called a cutting blow-pipe or torch. Hence the process is primarily a chemical one, based on the remarkable chemical affinity of oxygen for ferrous metals, when raised to, or above, the kindling temperature. The oxide of iron formed in flame-cutting is a black, brittle substance, identical in composition with hammer scale or magnetite ore. Its chemical formula is FE_3O_4. In addition to the chemical reaction in cutting, there is a noticeable and helpful mechanical eroding effect produced by

the kinetic energy or motive power of the cutting oxygen stream. This washes away considerable of the molten metal in unoxidized or metallic form, and adds to the efficiency and economy of the process. In the case of carbon steel, the metal is preheated to a bright red color, in daylight, a condition reached approximately between 1400 and 1600 deg. F. Only the metal within the direct path of the oxygen stream is acted upon. In linear cutting, or severing, a narrow race, or kerf, as it is usually called, is formed, having uniformly smooth and parallel walls. Where the torch is held firmly and advanced at uniform speed, as in machine flame-cutting, under skilled workmanship, cross-cut tolerances can be kept within narrow limits. In ordinary steel of 6 inches in thickness, for example, cut surfaces can be held true as to cross-sectional squareness to within 1/32 in. Cuts in thinner sections can be held within proportionately smaller limits. Machine flame cuts can be made so smooth and square and with such sharp edges that, for many applications, they require no further finishing of any kind.

Effect On Steel. — There is no detrimental effect when low and mild carbon non-alloy steels, containing less than 0.35 per cent carbon, are flame-cut. Indeed, flame-cut edges of such steels are suitable for any uses where edges prepared by any of the mechanical methods of severing are employed, as, for example, planing, milling, shearing, friction sawing, or grinding. In an exhaustive investigation conducted by the A.S.M.E. Boiler Code Committee several years ago, the results obtained were so conclusive that all restrictions in the Boiler Code pertaining to welding on flame-cut surfaces were removed. One of the important advantages brought out was that, where plate edges are beveled by flame-cutting and later welded together, the heat of welding anneals the base metal for an appreciable depth below the cut surface. This eliminates any change that may have been produced by the preceding flame-cutting in the crystalline grain structure of the steel. Higher carbon and alloy steels are apt to be affected detrimentally by flame-cutting, unless proper precautions are taken. When such steels are flame-cut at room temperature, a thin layer or zone of hardened material may be produced on the cut surfaces. This is sometimes quite brittle, or at least not sufficiently ductile to withstand the stresses set up in cooling or in subsequent use without cracking. By proper heat treatment, however, this brittle condition is readily overcome.

Preheating and Post Annealing.—As the steel at the cut edge is heated by the flame, it tends to expand, but is restrained by the adjoining cold metal. The action called "upsetting" results. Then, when cooling occurs, the upset metal contracts and considerable stresses may be produced. In the case of higher carbon and alloy steels, the ductility near the cut edge may not be sufficient to prevent cracking. However, if certain of the higher carbon and alloy steels are preheated to a temperature of about 500 to 600 deg. F. before flame-cutting, the cracking will not take place. This is because the difference in expansion between the metal heated during cutting and the adjoining preheated metal is less, which in turn reduces the stresses set up during subsequent cooling. Also, the cooling rate of the steel at the cut edge is retarded and the formation of troostite and martensite pre-

vented. Preheating expense is partly compensated for by the increased cutting speed possible at elevated temperatures. Post annealing completely restores the original pearlitic structure of the steel at the cut edges, wherever this may be desired, and removes any internal stresses set up in the metal. If carried out, it should be done immediately after flame-cutting. Annealing temperatures suitable to the type of steel in the piece, ordinarily in the neighborhood of 1250-1450 deg. F., are employed. Annealing time depends on the grade of steel, its thickness and shape. When preheating has been used before flame-cutting, the majority of steels do not require post annealing.

Flame-Softening.—Localized, progressive heating and heat-treatment have also been found effective in preventing or correcting undesirable structure in the cut edge. This process has been termed "flame-softening." It employs multiple oxyacetylene flames which are manipulated about the cutting zone to effect the desired heat-treatment, either simultaneously with the cutting operation or subsequent to it. Flame-softening can be applied to the top surface of the plate only, to both top and bottom surfaces simultaneously, or directly to the face of the cut, after the scrap has been removed or the kerf opened to admit the flame-softening apparatus. The most effective and economical method to employ in each case will depend upon the dimensions and composition of the metal to be treated, the service for which the part is intended, and other factors.

Machine Flame-Cutting.—The substitution of mechanical for manual torch operation, wherever practicable, effects better workmanship and greater economy and accuracy. Flame-Cutting machines have been developed which are capable of making cuts with jig-saw flexibility and of extremely high quality and accuracy. These include manual or motor-driven, partly or almost fully automatic, portable or stationary types, of various capacities. Some are equipped with two, or as many as six cutting torches, centrally controlled and guided, and will flame-cut a like number of identical shapes simultaneously. Machine flame-cutting is even simpler than free hand flame-cutting. Once the cutting speed and gas pressures have been set, the operation is almost automatic. As the cut progresses, the operator watches the drag and the flow of slag or oxide to prevent pockets or other defects from developing. For oxyacetylene machine flame-cutting of mild steel, speeds and gas pressures given in Table I are suggested. This table represents fair average practice and includes gas consumptions. Skilled operators working under favorable conditions can do considerably better than the table indicates.

Flame Machining.—This process utilizes the same fundamental principle of chemical reaction, but the relatively low velocity cutting oxygen stream is made to impinge on the work at a more or less acute angle; in some cases, almost tangentially. The cut is not permitted to penetrate through the work as in severing, but is restricted to removal of a predetermined depth and width of material from the surface by oxidation. Deseaming, or scarfing of billets, slabs and rounds in steel mills, is the principal application of flame machining at present.

TABLE I.—MACHINE FLAME-CUTTING MILD STEEL—¼ to 12 inches**

Thickness of Steel In.	Cutting Oxygen Pressure* Psi	Cutting Speed In. per Minute	Gas Consumptions			
			Per Hour		Per Linear Ft.	
			Oxygen Cu.Ft.	Acetylene Cu.Ft.	Oxygen Cu.Ft.	Acetylene Cu.Ft.
¼	11–35	20–28	45–93	8–11	0.45–0 66	0.08–0.08
½	20–55	17–24	105–125	10–13	1.04–1.24	0.11–0.12
¾	24–50	15–22	117–159	12–15	1.45–1 56	0.14–0.16
1	28–55	14–19	130–174	13–16	1.83–1.86	0.17–0.19
1½	55	12–15	240	14–18	3.20	0.23–0.24
2	22–60	10–14	185–260	16–20	3.70–3.72	0.29–0.32
3	33–50	8–11	240–332	18–23	6.00–6.04	0.42–0.45
4	42–60	6.5–9	293–384	21–26	8.53–9.02	0.58–0.65
6	45–65	4.5–6.5	400–490	26–32	15.10–17.78	0.98–1.16
12	69–105	2.4–3.5	720–880	42–52	49.70–60.00	2.97–3.50

*Acetylene pressure is more a function of torch design than of thickness being cut. Therefore, it has been omitted.

**Not preheated.

Other Flame-Cutting Processes.—Several other types of controlled oxidation are in use, which employ the free-burning reaction of oxygen with ferrous metals, raised to kindling temperature, to provide means of severing, shaping and working such materials. One such application, known generally as "oxygen lance cutting" utilizes a relatively long section of small-diameter iron pipe. The end of the pipe is ignited and kept so by a stream of oxygen flowing through the pipe. This furnishes preheat as well as free oxygen for cutting, thus forming a lance-like cutting tool which is used primarily for emergency and heavy-duty cutting, such as opening up furnace tap holes and making starting holes for internal flame-cuts in pieces.

ARC CUTTING

The cutting of steel is a chemical action. The oxygen combines readily with the iron to form iron oxide. In cast iron this action is hindered by the presence of carbon in graphite form. Thus cast iron cannot be cut as readily as steel: higher temperatures are necessary and cutting is slower. In steel, the action starts at bright red heat, whereas in cast iron the temperature must be more nearly melting point in order to obtain a sufficient reaction.

Due to its very high temperature, the electric arc is suggested for cutting cast iron. This method may be used also in cutting metals such as manganese steel and non-ferrous metals. The rate of cutting is usually fairly high. However, as the process is essentially one of melting without any great action tending to force the molten metal out of cut, some provision must be made for permitting the metal to flow readily away from the cut. This is usually done by starting at some point from which the molten metal may readily flow. This method is followed until the desired amount of metal has been melted away.

As an example, the general method is to apply the electric arc on under side of the work, starting at a lower corner, working toward the center on the lower surface, and then up the side, repeating this action as many times as necessary. This will allow the molten metal to flow out of the cut.

Carbon electrode is generally used. Graphite electrodes are used to some extent because they permit use of higher currents. Shielded arc type electrodes are also effective. In starting a cut, the arc is held at the point selected for the initial cut as, for example, a lower corner. When the metal begins to flow and run off, the arc is moved along at a rate to permit the metal to continuously flow out of the cut.

The width of the cut is dependent upon the ability of operator to follow a straight line, the size electrode used, and the thickness of material. The width of the cut is greater on thick sections than on thin.

In the above discussion the ease with which steel may be cut has been noted. Other metals, which are difficult to cut by ordinary methods due to their reluctance to oxidize, may be cut readily and economically by the electric arc because of its high temperature and its comparatively low cost of heat production.

PART III

PROCEDURES, SPEEDS AND COSTS

PART III

PROCEDURES, SPEEDS AND COSTS

The proper procedure to be followed for welding different types of joints varies according to the arc welding process employed, the position of the work, the material to be welded, and the physical requirements of the weld. The speed of welding and weld costs are also influenced by the above factors.

In general all welds may be placed in one of two classifications or both:

(1) Welds produced principally by deposition of filler metal. Welds which fall into this class are, V'd butt welds and fillet welds. (See Page 40.)

(2) Welds produced principally by fusion of base metal. Typical examples of this class of welds include square butt welds, lap and edge welds. (See Page 40.)

Welds which combine both classifications are those in joints scarfed to a depth materially less than the thickness of the base metal.

In general the most economical method of making a weld will be an economic balance between:

(a) Preparation (such as bevelling, scarfing, etc. See Page 205).

(b) Welding, (involving labor, materials and power).

The size of electrode will generally be the largest that can be used for the type of joint under conditions outlined in first paragraph. The proper current will not be the maximum that can be used on the electrode but will be that value which produces the maximum rate of deposition consistent with the quality of weld desired.

The most economical method of making the second (2) class of welds generally will be with that type of electrode which produces the best penetration into the base metal. The size of electrode will be the largest that can be used for satisfactory penetration and quality of joint. The current used generally will be considerably more than for the (1) type described above and will be as high as is consistent with the quality of weld desired.

The data given in the following pages contain only typical applications which are most commonly used in welding by manual process with the shielded arc, with bare or washed electrodes or with the automatic process (shielded carbon and metallic arcs).

PROCEDURE, SPEEDS AND COSTS FOR MANUAL WELDING WITH SHIELDED ARC

The great variety of welding applications in which different types of welds are made in all positions, makes it practically impossible to give exact procedures for each application. However, the general procedures which follow will apply to most welding work. The typical applications given with outline of proper procedure are for general guidance. Any specific application should be studied carefully and the general procedure modified to obtain quality of weld desired.

THE SPEEDS given in these selected procedures or applications are results of many actual tests and are, therefore, true average arc speeds. THE SPEEDS ARE FOR ACTUAL ARC TIME ONLY WITH NO ALLOWANCE FOR FATIGUE, CLEANING, SETTING UP, ETC., as these items vary greatly in different shops. These factors must be taken into account in obtaining the production speed. The data given are based on the use of a well-known shielded arc electrode. The data and procedure may, therefore, vary when other electrodes of the shielded arc type are used.

It should be noted that the arc voltage given is the actual voltage across the arc while delivering the specified current. The currents designated are those used to obtain the stated speeds. Any variation in current from those given will affect the welding speeds. Also the amount of electrode per foot will vary greatly depending upon fit-up and other conditions, and the figures given are intended as a guide only.

Polarity of Welding Current.—The polarity of the welding current is sometimes spoken of as "straight" or "reversed". In "straight" polarity, the electrode is negative and the work positive; in "reversed" polarity, the electrode is positive and the work negative. The terms "electrode negative"—"electrode positive" are more definite and will be used in this text. Electrode negative is used in welding with bare or lightly coated electrodes due to the fact that with such electrodes somewhat more heat is generated on the positive side of the circuit. However, the addition of a coating to the electrode forms gases in the arc and the presence of these gases may alter the heat conditions so that the opposite is true; namely, the greater heat is produced on the negative side. Nevertheless, the heat conditions are affected differently by different types of coatings. One type of heavy coating may provide the most desirable heat balance with electrode negative while another type of coating on the same electrode may provide a more desirable heat balance with electrode positive.

Both are frequently used. The polarity to use with a particular electrode is established by the electrode designer. When doubt exists as to the correct polarity to use, the burn-off rate of the electrode will serve as a good guide. Each polarity is used to burn off 6″ or 8″ of electrode. The polarity which results in the longer burn-off time is generally the one which produces greater heat in the plate or joint. This is desirable in some cases while in others it is desirable to use the polarity which produces less heat in the plate.

The above refers only to welding with direct current. With alternating current, since polarity changes very rapidly, the electrode must be suitable for use with either polarity. This does not mean, however, that a negative or positive polarity electrode will not be satisfactory with alternating current. As a matter of fact, a shielded arc electrode of high quality will provide satisfactory results on alternating current, even though it is designed for use with direct current.

The elimination of craters at completion of bead or when electrodes are changed can be accomplished by withdrawing the electrode slowly at a right angle until arc is broken. To start a new electrode the arc should be struck just ahead of the end of bead and after a short interval moved backwards to completely remelt end of bead and fill up any crater

which might have occurred. Welding should then proceed forward as usual.

Where weaving is specified, a motion similar to the diagram, Fig. 191, should be used. There should be a hesitation in the motion for a short interval at the sides of the scarf.

The advance of the arc should be at such a rate that all undercutting is filled up. The rate of advance can be determined by watching the solidifying metal; care should be taken not to advance the arc too rapidly.

Arc blow may cause an uneven burning of the electrode coating which in turn will result in improper fusion and gouging. Where arc blow is present it can almost always be compensated for by shifting the ground connection to another part of the work.

Weld should be allowed to cool between welding of succeeding beads. Better results are generally obtained if this is done. In the heavier plates and long seams the bead will usually cool sufficiently in the natural

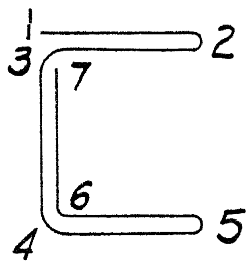


Fig. 191. Diagram of weaving motion of electrode.

course of procedure before the next bead is deposited. However, in short heavy sections the time for cooling allowed by uninterrupted procedure may not be sufficient. Allowance for proper cooling will facilitate removal of slag.

Slag removal can be accomplished easily by scraping with corner of a chisel or file along the edges of the weld. A large amount of the slag will crack off as a result of this scraping. Slag removal may be completed by use of a wire brush. Other means of removing slag such as sandblast or air hammer, may be used. Slag should be completely removed from each bead before succeeding beads are deposited.

Where paint is to be applied over the weld, slag should be removed preferably by grinding or sand blasting. Because most of the slags are basic, some of them containing free alkali, it is necessary to scrub the weld and adjacent plate area with water or to neutralize the weld area with weak acid solutions such as 10% HCL and then wash off the acid solution with water. Otherwise, unless alkali-resisting paint is applied, the paint will deteriorate through chemical action.

When welding plates or shapes of unequal thickness, the arc should be directed in such a manner so that both pieces being welded are heated equally, the arc being generally directed against the heavier section.

It is of great advantage to set up the work so that the molten pool

of weld metal is horizontal. This will almost always result in an increased speed of welding. Often the use of fixtures designed to allow most or all of the welding to be done in a horizontal position is justified by the increase in weld production. (See Page 211.)

For vertical or overhead welding, 3/16" and smaller electrodes are generally used. In some cases a slightly different type of electrode is used for welding in these positions.

The selection of the direction of welding for vertical joints involves not only the direction of welding, but also the characteristic of the resultant bead and joint. Generally, it is easier to weld down. On certain joints it is quite difficult to weld up without use of a backing-up strip. For example, on a single-vee butt weld it is very difficult to put in the first bead when welding up. When a backing-up strip is used, or the weld is a fairly heavy fillet, or the type of joint has good heat capacity, welding up may be done fairly easily. Care must be taken to eliminate slag and incomplete fusion at side of bead and avoid undercutting.

Welding down produces a concave bead, with practically no undercutting, and fine grain structure due to multiple beads, with resulting greater cleaning time because of the greater number of beads. On the other hand, welding up produces a more abrupt change in contour at the toe of the bead. The bead is convex and fusion is more easily obtained at the heel of the bead.

From the above it is obvious that to recommend only one direction of welding is impossible unless the type of joint, the type of electrode, and what is required in the completed joint, are known.

There are certain results which should be considered before the direction of welding is selected.

The principal in welding up is, in general, to allow sufficient time for the molten metal to solidify and to then deposit additional metal on the solidified metal. This is done by moving electrode up and away from molten pool without interrupting the arc and by keeping arc away from pool until the metal becomes solid or non-fluid. This requires a fraction of a second, following which the arc is returned to this non-fluid metal and another deposit made.

General Technique for Welding Small Beads Up.—In general, for given size electrode the same current is used regardless of the direction of welding. Consequently for a given setup the final speed of welding is approximately the same for both directions.

For welding small beads upward use recommended size electrode and current. Strike arc and build what may be termed a shelf the same size as the required weld. Just before metal begins to spill off, and not before, run electrode up quickly 3/8" to 3/4" without breaking the arc. As soon as metal on shelf solidifies bring electrode down and again deposit metal. While depositing metal, hold a relatively short arc so as to reduce tendency of undercutting. Also move the electrode from side to side to aid in obtaining proper fusion and size of bead. This cycle is repeated until weld is completed. When changing electrodes be careful to obtain proper fusion of metal into the shelf.

General Technique for Welding Large Size Beads (Above 3/8").—In welding large size beads—above 3/8"—strike arc and build shelf by

weaving electrode full width of required bead, hesitating at side of bead until molten metal on opposite side solidifies. It may be necessary to traverse the arc up the scarf to allow time for metal previously deposited to become solid. As soon as metal is deposited on one side move electrode to other side of bead and deposit metal there until the previously deposited metal has become solid. Be careful to obtain good fusion and avoid undercutting. When changing electrodes, make sure of proper fusion into the shelf.

Note: The method outlined under small beads may be used on fillet welds for practice in overcoming undercutting. Proceed as outlined and gradually reduce the travel of the electrode until there is no movement and bead is deposited in a straight run.

For bead procedure in welding a particular joint, either up or down, refer to that type of bead in the following pages.

In both vertical and overhead welding the electrode should be held at right angle to the work. To make sure of 100% penetration of a vertical weld, sometimes a small bead is deposited on the back of the welded joint after the front beads have been run. Before doing this it is advisable to run a diamond point down the back of the joint until weld metal is reached. This will insure 100% penetration and eliminate slag inclusions.

For quick reference the charts on the following pages show the actual arc speed in lineal feet per hour and the pounds of electrode required, including stub ends (2″) per lineal foot of weld for plain butt joints, single Vee butt joints, lap joints and tee joints welded with a shielded arc type electrode.

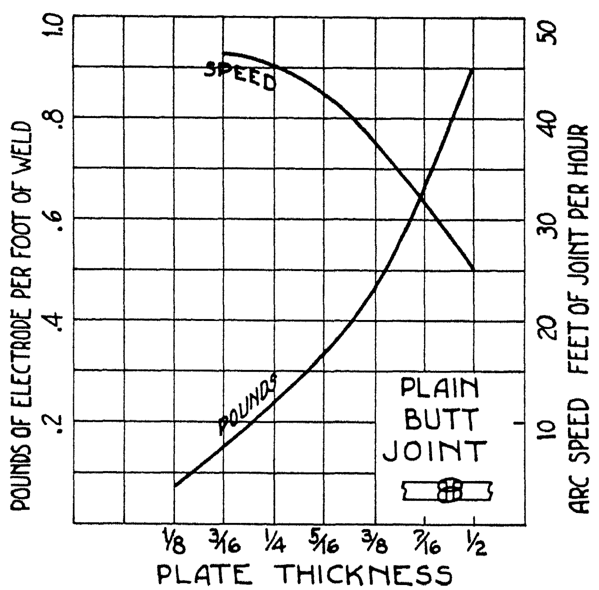


Fig. 192. Chart of welding speed and amounts of shielded arc type "A" (flat bead) electrode for square groove butt joints.

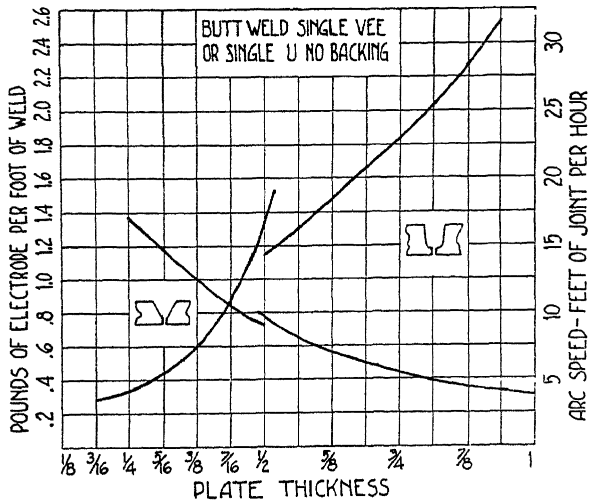


Fig. 193. Chart of welding speed and amounts of shielded arc type "A" (flat bead) electrode for welding single vee or single U-groove butt joints.

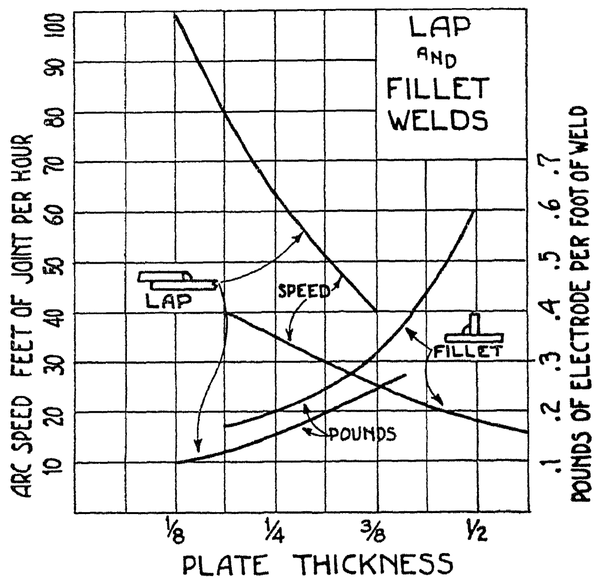


Fig. 194. Chart of welding speed and amounts of shielded arc type "A" (flat bead) electrode for fillet and lap joints.

METHOD OF DETERMINING AMOUNT OF CURRENT CARRIED BY ELECTRODE

Often the location of the welding is at considerable distance from the welding machine and in such cases it is impossible or inconvenient to check the arc amperage by reading the ammeter during inspection of the welding in progress. In such cases a quick and easy method

of determining the amount of current carried by the electrode is desirable. Also by such a method the accuracy of the meter on the welder may be checked, because due to possible rough handling of the welder the delicate mechanism of the meter may be thrown out of proper adjustment. A watch with second hand and a chart, see Fig. 195, which may be prepared by the following method, are the only tools needed.

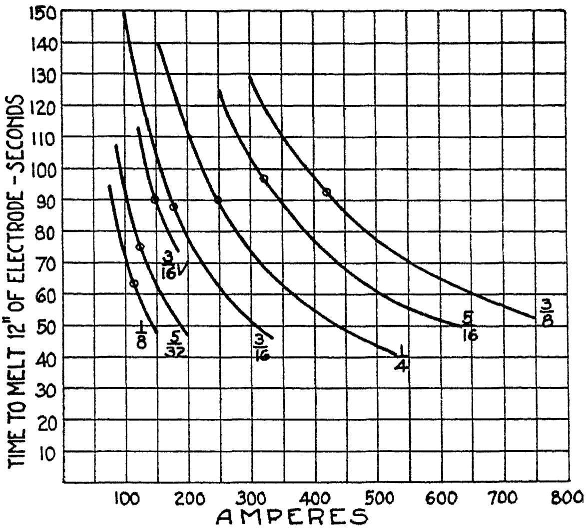


Fig. 195. A typical chart as used in the determination of current carried by an electrode.

Considering a popular type of shielded arc electrode it has been found that for a given size electrode the burn-off rate is approximately proportional to the current. The effect of voltage may be neglected, because under usual conditions it is negligible. The melting or "burn-off" is the same for a given size of electrode and current regardless of position.

By securing from the manufacturer of the electrode the recommended current value, also the maximum and minimum current values for this electrode, and then by actual test determining the number of seconds required to burn off 12 inches of this electrode at minimum current value, recommended current value and maximum current value, the time may be plotted against the amperes on a chart similar to the chart, Fig. 195. The complete curve for any given size of electrode may then be secured by determining the time required to burn off 12 inches of electrode at several intermediate amperage values. The results then plotted on the chart will furnish sufficient points from which to secure a complete curve as shown. Curves for all the various sizes of electrodes may be plotted by this method. The chart is then ready for use.

How to Use the Chart.—1. Clock the time required to burn off 12 inches of the electrode in question. 2. From this time point on the

time scale of the chart, project a horizontal line to the curve representing the size electrode used. 3. From the point of intersection of the horizontal line with the curve, project a vertical line to the amperage scale. 4. The point of intersection of this vertical line with the amperage scale indicates the amount of current being carried by the electrode in question.

CHOICE OF ELECTRODES

It is recommended that the reader familiarize himself with the American Welding Society filler metal specifications. See Page 366.

The selection of an electrode most suitable for a particular purpose or requirement and its proper application thereto, results in low cost fabrication and efficient performance.

To make most efficient selection, it is necessary to know—

Physical properties required, etc.

Type of joint (see Page 40).

Position in which the weld is to be made, i.e., flat, vertical or overhead.

Condition of work fit-up, etc.

Electrodes may be classified in various ways. For example:

1. Mechanical characteristics such as tensile strength, ductility, etc.
2. Method of use, such as position in which they are to be used, i.e., flat, vertical, overhead, horizontal.
3. Type of the joint, such as fillet, deep groove, etc.
4. Shape of the bead, such as flat, convex, or concave.

The shape of the bead is a common method of classification, since the service or operating requirements determine the shape of the joint of which the bead is a part.

For convenience in this discussion, we will designate these classes as follows: (1) flat bead, Type A; (2) convex bead, Type B; (3) concave bead, Type C.

The weld metal deposited has certain common characteristics. The endurance limit is high, running in the neighborhood of half the tensile strength. The specific gravity runs generally from 7.84 to 7.86. The impact strength is also high, averaging 30 to 80 foot pounds Izod.

Type A, Flat Bead—This type may be classified as a general purpose electrode as it is used for a wide variety of work and possesses high average mechanical characteristics. It has a heavy coating. It is best suited for direct current with electrode positive. In sizes, 5/32" and smaller, it is suitable for use in all positions. A 3/16" size is also made special for all-position welding. It is suitable for fillets, deep grooves, and all types of joints in all positions. It has deep penetration qualities and is used very satisfactorily on square-groove butt joints where the electrodes actually *scarf or melt the plates.* It produces a rather flat bead of the general type as shown in Figure 196.

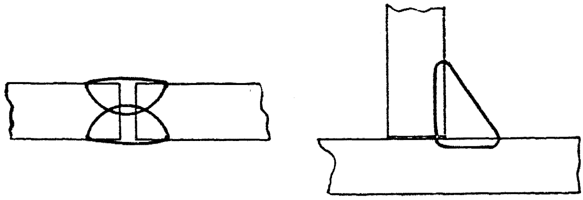


Fig. 196. Flat beads produced by a type "A" electrode.

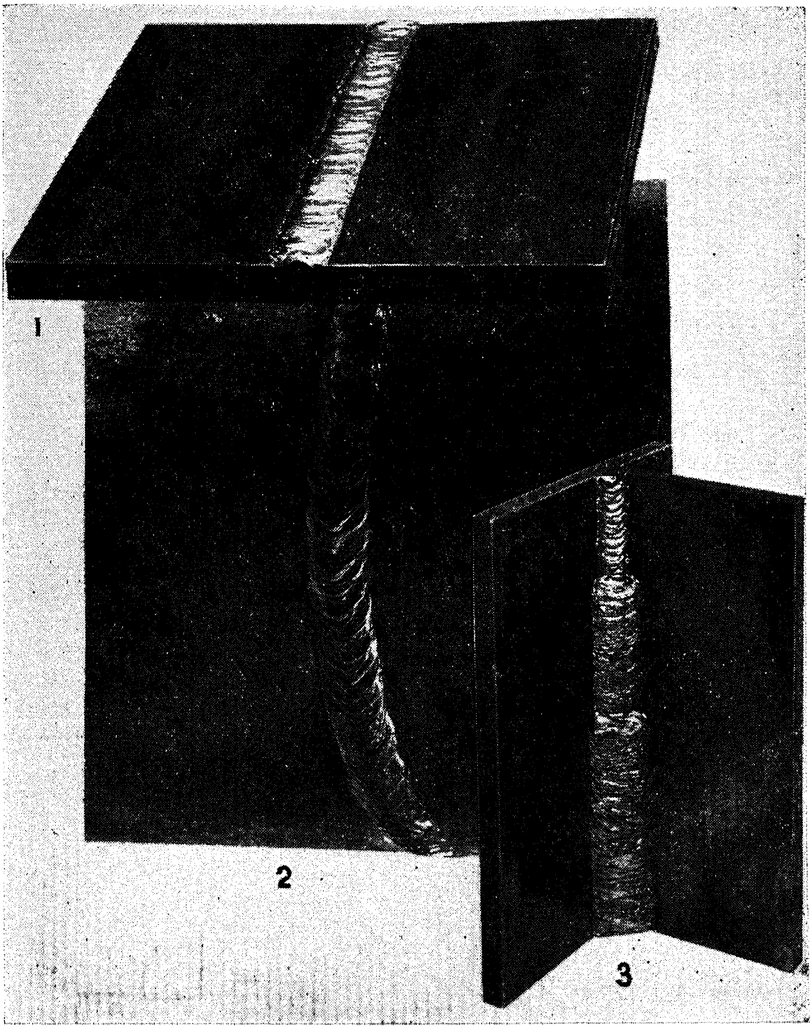


Fig. 196-A. Welds produced with Type A Electrode. (1) Downhand weld in square groove butt joint in ¼ in. plate. (2) Three position weld in 6-in. pipe with V-groove joint. (3) Vertical fillet weld in ⅜-in. plate showing three passes.

Of the same general characteristics are several electrodes for welding the low alloy, high-tensile steels.

In this group are the following electrodes as designated by the American Welding Society in their Filler Metal Specifications.

A.W.S. Classification No.	For Positions*	General Description	Treatment of welded specimen† (a)	All Weld Tension (b) Lbs. p.s.i.	% El. in 2"
E6010	F,V,OH,H	Heavy covering useful with D.C. electrode positive only.	SR NSR	60,000 65,000	27 22
E7010	V,F,OH,H	Heavy covering, useful with D.C. electrode positive only.	SR NSR	70,000 75,000	22 17

*F=flat; V=vertical; OH=overhead; H=horizontal.
†SR=stress relieved; NSR=not stress relieved.

In this same group is an electrode in a higher range, giving 90,000 to 105,000 lbs. per sq. in. ultimate tensile strength and elongation of 12% to 22% in two inches.

Type B, Convex Bead—This class of electrode has a heavy coating, is used with direct current with the electrode negative, or it may be used with alternating current. Sizes of 5/32" and smaller are suitable for all positions, and in larger sizes for welding in flat positions. It may be used for fillet welding, single or multiple pass, and can be used for butt welds of the V-groove or U-groove type. Due to its deposition characteristics and ability to build up, it is used to fill gaps in cases of poor fit-up. The penetration is somewhat less than with the Type A electrode (flat bead) and the spatter is somewhat less. It possesses a somewhat higher ultimate tensile strength and a slightly less ductility. Because it does not penetrate deeply, it is used in cases where an in-wash of a base metal is not desirable or required. It produces a somewhat convex bead as indicated in Fig. 197.

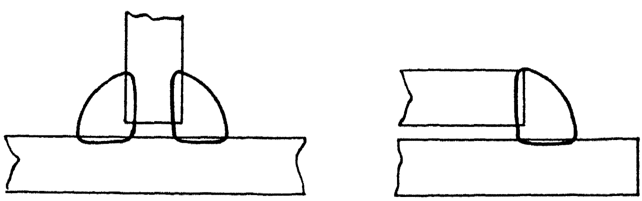


Fig. 197. Convex bead produced by a type B electrode.

This type of electrode is designated in the American Welding Society Filler Metal Specifications as follows:

A.W.S. Classi-fication No.	For Positions	General Description	Treatment of welded specimen (a)	All Weld Tension (b)	
				Lbs. p.s.i.	% El. in 2"
E6012	F,V,OH,H	Heavy covering usually used with electrode negative D.C., or on A.C.	SR NSR	60,000 65,000	22 17

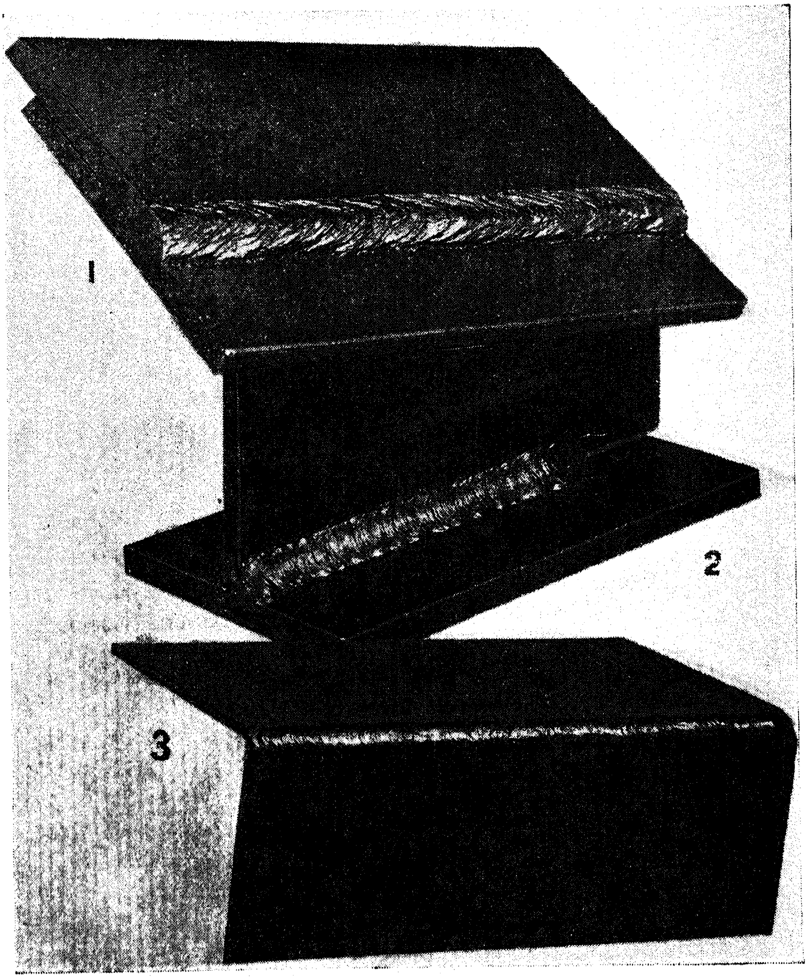


Fig. 197-A. Welds produced with Type B Electrode. (1) Lap weld in 3/16-in. plate. (2) Fillet weld in 3/16-in. plate with 1/16-in. gap (poor fit-up). (3) Corner weld in ⅛-in. plate.

Type C, Concave Bead—This type of electrode has a heavy coating and can be used with direct current with either positive or negative polarity and can also be used with alternating current. It is used in the flat position only and is not suitable for vertical or overhead work although under special conditions as to setup, such as 30° from vertical, it may be used for fillet, welding downward. This type is used for fillets or butt joints of the V-groove or U-groove types. It flows very readily with a heavy slag covering the weld. It is sometimes known as the "hot rod" type. It produces a very smooth bead, slightly concave, and in some cases very concave. See Fig. 198.

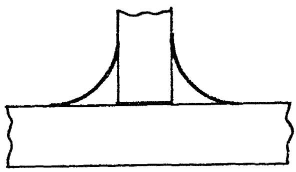


Fig. 198. Concave bead produced by type C electrode.

In this general group are several different types, one usually used for fillets in the flat or horizontal position, another for U-groove work.

It is also made in this type for the high-tensile low-alloy types of steel.

In this same group is another electrode known as a finish-pass or last-pass electrode, which is used to provide an exceptionally smooth last bead on a multiple pass U-groove joint. See Fig. 199.

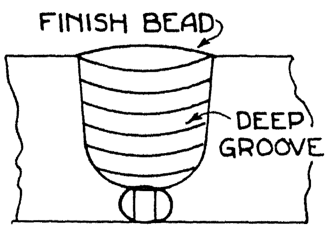


Fig. 199. Finish-pass bead produced by a type C electrode.

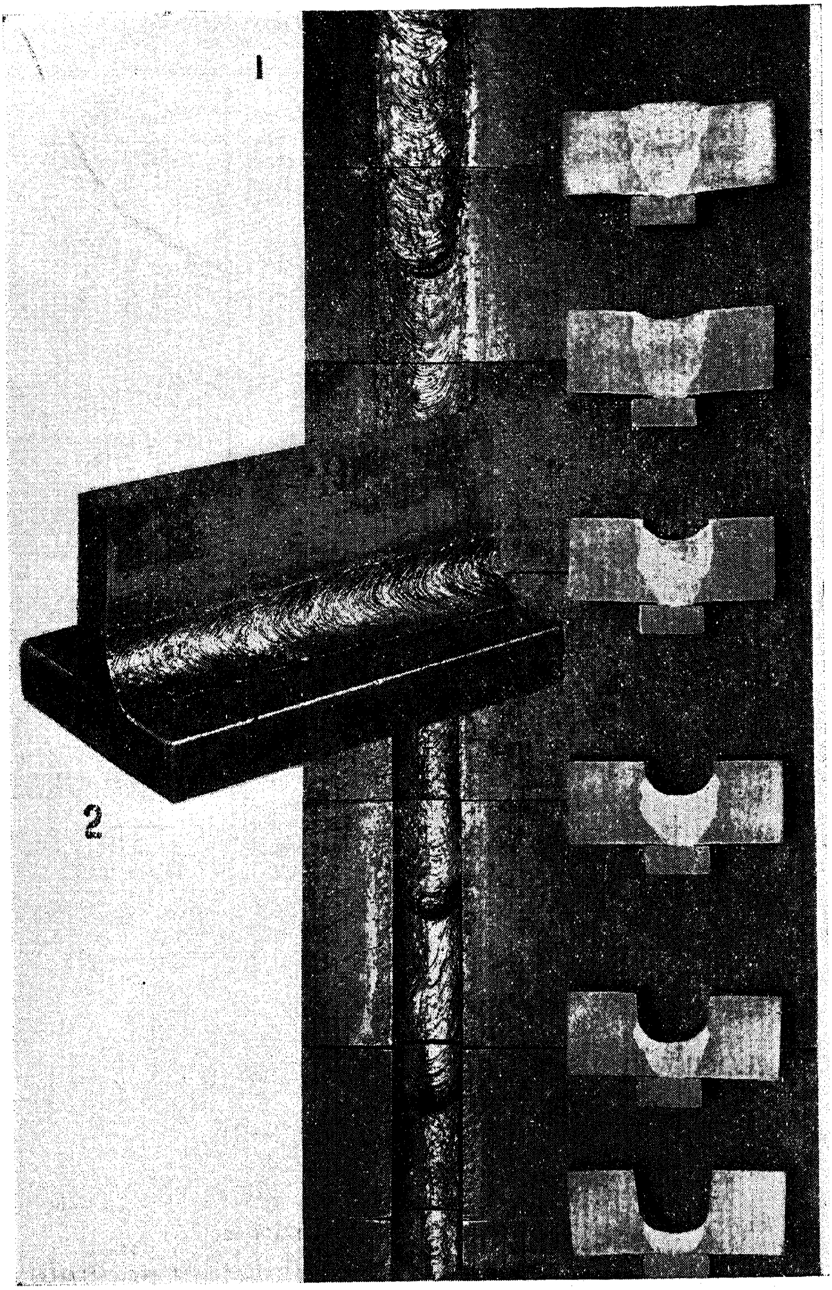


Fig. 199-A. Welds produced with Type C Electrode in mild steel. (1) Deep groove joint showing cross-section of various passes. (2) Fillet weld in ½-in. plate, tilted position.

Designations for these various types as given in the Filler Metal Specifications, The American Welding Society are as follows:

A.W.S. Classification No.	For Positions	General Description	Treatment of welded specimen (a)	All Weld Tension (b) Lbs. p.s.i.	% El. in 2"
E6020	H-Fillets, F.	Heavy covering usually used with electrode negative or A.C. for fillets and electrode positive or A.C. for flat welding	SR NSR	60,000 65,000	30 25
E6030	F	Heavy covering usually used with electrode positive on D.C., or with A.C.	SR NSR	60,000 65,000	30 25
E7030	F	Heavy covering usually used with electrode positive D.C., or with A.C.	SR NSR	70,000 75,000	25 20

In addition to types given above, there is still another type with a heavy coating which is generally used with alternating current. This type, while generally used with A.C., also works well with D.C. American Welding Society Filler Metal Specifications designate this as:

A.W.S. Classification No.	For Positions	General Description	Treatment of welded specimen (a)	All Weld Tension (b) Lbs. p.s.i.	% El. in 2"
E6013	F,V,OH,H	Heavy covering usually used on A.C.	SR NSR	60,000 65,000	22 17

PROCEDURES FOR TYPE A ELECTRODES (FLAT BEAD)

Type A Electrode for Mild Steel

The following procedures, Pages 154 to 179, inclusive, are for a well-known Type A electrode of flat-bead characteristics (E6010).

V'd Butt Welds, Flat Position.—The requirements of weld are 100% penetration, 100% strength. They are made with no backing and are welded from one side only, see Figs. 200-202.

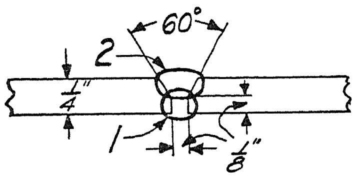


Fig. 200.

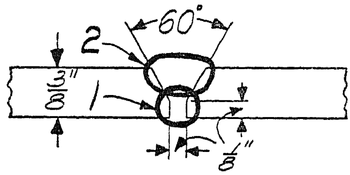


Fig. 201.

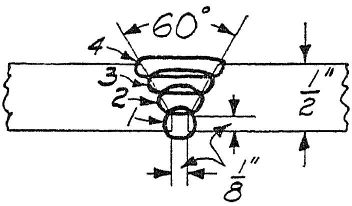


Fig. 202.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed, Ft. of Bead Per Hr.	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 200	1	5/32"	130	25	45		.11
1/4" plate	2*	3/16"	175	28	25	17.5	.25
							.36
Fig. 201	1	5/32"	130	25	32.5		.15
3/8" plate	2*	1/4"	225	30	20	13	.43
							.58
	1	5/32"	130	25	30		.16
Fig. 202	2	1/4"	225	30	36		.24
1/2" plate	3	1/4"	275	30	40	9	.26
	4	5/16"	325	34	38		.35
							1.01

*Weave this bead.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

V'd Butt Welds with Backing, Flat Position.—The requirements of type of weld, illustrated in Figs. 203 and 204 are 100% strength and 100% penetration. They are welded from one side into a steel backing strip or chill band.

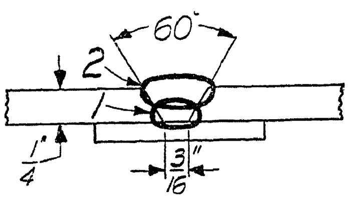


Fig. 203.

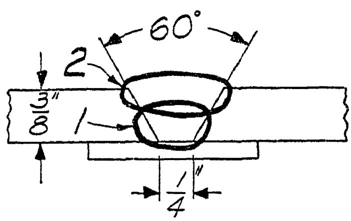


Fig. 204.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed, Ft. of Bead Per Hr.	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 203 1/4" plate	1 2	5/16" 3/8"	325 425	34 38	75 60	33.5	.172 .325 .497
Fig. 204 3/8" plate	1 2	5/16" 3/8"	325 425	34 38	65 45	27.5	.198 .44 .638

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Plain Butt Welds, Flat Position.—This type of weld is divided into two classes—one class where it is possible to weld from only one side or where only 50% penetration is necessary; the second class where it is possible to weld from both sides and where 100% penetration is desirable or necessary. The metal structure in this type of weld varies with the analysis of the material welded.

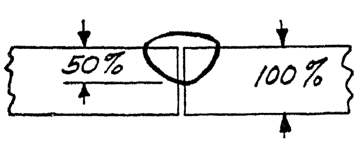


Fig. 205.

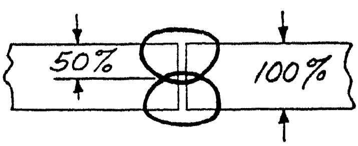


Fig. 206.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed, Ft. of Bead Per Hr.	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 205 3/16" plate	1	1/4"	190	30	90	90	.078
Fig. 206 3/16" plate	2	1/4"	190	30	94	47	.16
Fig. 205 1/4" plate	1	5/16"	300	34	90	90	.133
Fig. 206 1/4" plate	2	5/16"	300	34	90	45	.27
Fig. 205 3/8" plate	1	5/16"	425	38	75	75	.226
Fig. 206 3/8" plate	2	5/16"	425	38	75	37½	.45
Fig. 205 1/2" plate	1	3/8"	500	40	50	50	.46
Fig. 206 1/2" plate	2	3/8"	500	40	50	25	.92

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Butt Welds in Heavy Plate, Flat Position.—In making various types of butt welds in heavy plate the following examples and procedures are typical and should serve as a general guide for welding in heavy plate of various thicknesses.

The work should be fit up as shown, the beads made in the position and in the order indicated.

In case of joints scarfed on both sides, first bead (1) should penetrate to the bottom edge of the plates. After turning over the work the first bead (1) should be peened with a blunt tool and thoroughly brushed. If the plates were not spaced properly the first weld may not show through from the other side of plates, in which case a diamond point chisel should be used until the weld metal is reached. Care should be taken not to chip too deeply or make a sharp Vee as incomplete fusion will result when welding second bead (1a). On completion of the second bead (1a) it should be peened thoroughly, especially along the edges and then well brushed. The work is then turned over and welding proceeds in the order indicated. Where it is impractical to turn the work after welding each bead, the welds should be made on one side in order indicated and then the work turned and the welding done as shown for the other side.

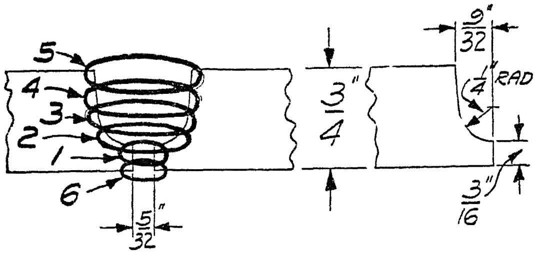


Fig. 207.

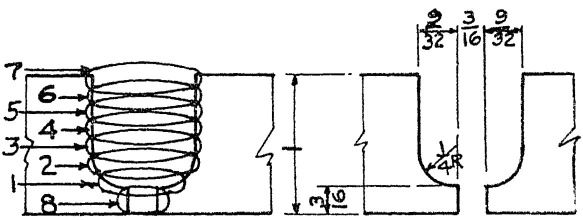


Fig. 208.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 207 3/4" plate	1	5/32"	130	25		
	2	1/4"	275	30		
	3	1/4"	275	30		
	4	1/4"	275	30		
	5	5/16"	325	34		
	6	1/4"	275	30	6	1.90
Fig. 208 1" Plate	1	5/32"	130	25		
	2	1/4"	275	30		
	3	1/4"	275	30		
	4	1/4"	275	30		
	5	1/4"	275	30		
	6	1/4"	275	30		
	7	5/16"	325	34		
	8	1/4"	275	30	3.6	2.4

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

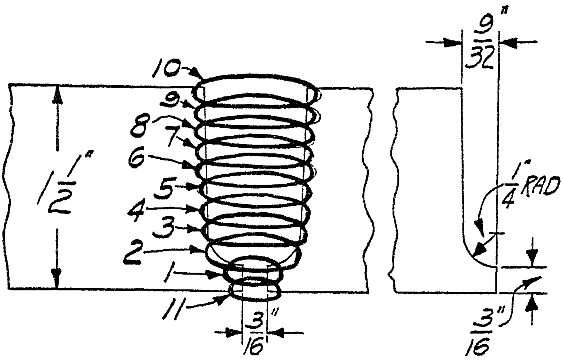


Fig. 209.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
	1	5/32″	130	25		
	2	1/4″	275	30		
	3	1/4″	275	30		
	4	1/4″	275	30		
Fig. 209 1½″ Plate	5	1/4″	275	30		
	6	1/4″	275	30		
	7	1/4″	275	30		
	8	1/4″	275	30		
	9	1/4″	275	30		
	10	5/16″	325	34		
	11	5/16″	325	34	2.5	3.70

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

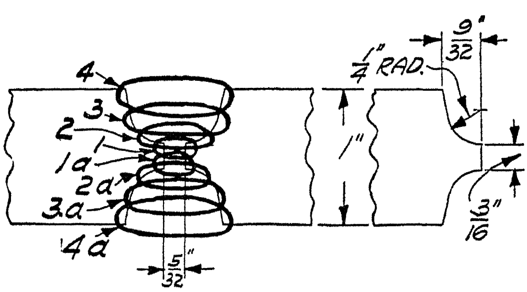


Fig. 210.

For 3-inch butt welds the plates should be scarfed and set up as shown in Fig. 211. Twelve beads should be welded on each side—a total of 24 beads in the 3-inch weld. For passes, 9-9a to 12-12a inclusive, 5/16″ electrodes should be used with 325 ampere current and arc voltage of 34. The actual welding speed should be 1 ft. per hr.; pounds of electrode per foot of weld, 7.2.

Joint	Beads or Passes	Elec-trode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 210 1″ plate	1	5/32″	130	25		
	1a	1/4″	275	30		
	2	1/4″	275	30		
	2a	1/4″	275	30		
	3	1/4″	275	30		
	3a	1/4″	275	30		
	4	5/16″	325	34		
	4a	5/16″	325	34	3 8	2.28
Similar to Fig. 211 1½″ Plate	1	5/32″	130	25		
	1a	1/4″	275	30		
	2	1/4″	275	30		
	2a	1/4″	275	30		
	3	1/4″	275	30		
	3a	1/4″	275	30		
	4	1/4″	275	30		
	4a	1/4″	275	30		
	5	1/4″	275	30		
	5a	1/4″	275	30		
	6	1/4″	275	30		
	6a	5/16″	325	34	2.8	3.3
Fig. 211 2″ plate	1	5/32″	130	25		
	1a	1/4″	275	30		
	2	1/4″	275	30		
	2a	1/4″	275	30		
	3	1/4″	275	30		
	3a	1/4″	275	30		
	4	1/4″	275	30		
	4a	1/4″	275	30		
	5	1/4″	275	30		
	5a	1/4″	275	30		
	6	1/4″	275	30		
	6a	1/4″	275	30		
	7	1/4″	275	30		
	7a	1/4″	275	30		
	8	5/16″	325	34		
	8a	5/16″	325	34	1.80	4.35

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

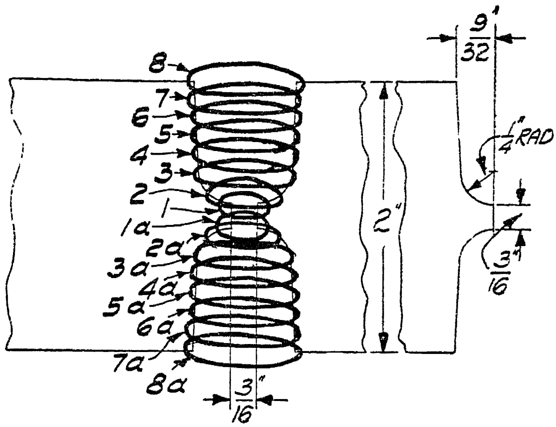


Fig. 211.

There is still a further type of butt joint which may be desirable and which may lend itself readily to certain applications; note the following sketches, Figs. 212, 213 and 214. Approximately full penetration is obtained in this type of joint.

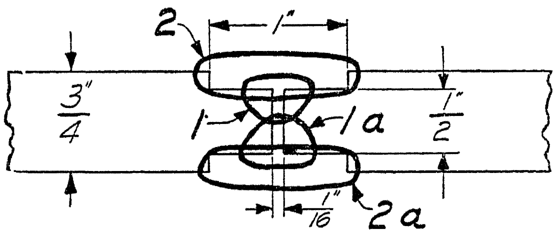


Fig. 212.

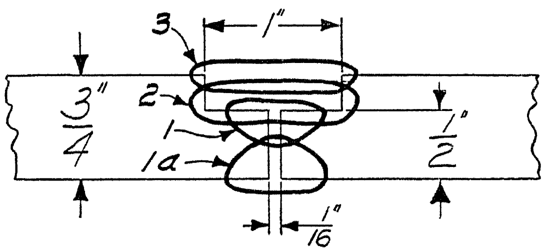


Fig. 213.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed, Ft. of Bead Per Hr.	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig 212 ¾" plate	1	⅜"	500	40	50		
	1a	⅜"	500	40	50		
	2*	⅜"	500	40	25		
	2a*	⅜"	500	40	25	8 3	2.80
Fig. 213 ¾" plate	1	⅜"	500	40	50		
	1a	⅜"	500	40	50		
	2*	⅜"	500	40	25		
	3	⅜"	500	40	25	8.3	2.80

*Weave this bead.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

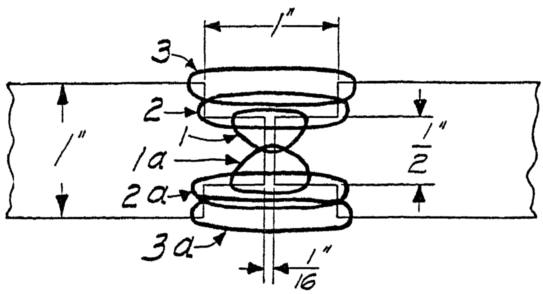


Fig. 214.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed, Ft. of Bead Per Hr.	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 214 1" plate	1	⅜"	500	40	50		
	1a	⅜"	500	40	50		
	2 *	⅜"	500	40	25		
	2a*	⅜"	500	40	25		
	3*	⅜"	500	40	25		
	3a*	⅜"	500	40	25	5.0	4.60

*Weave this bead.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

V'd Butt Welds in Tee Joints of Heavy Plate.—The same general procedure should be followed in making this type of joint as described for butt welds, Pages 157 and 161.

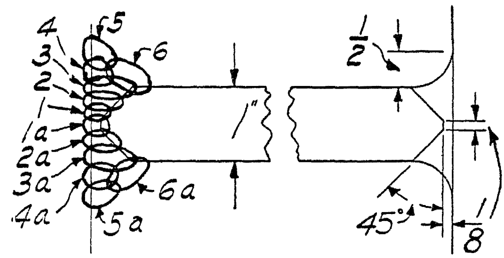


Fig. 215.

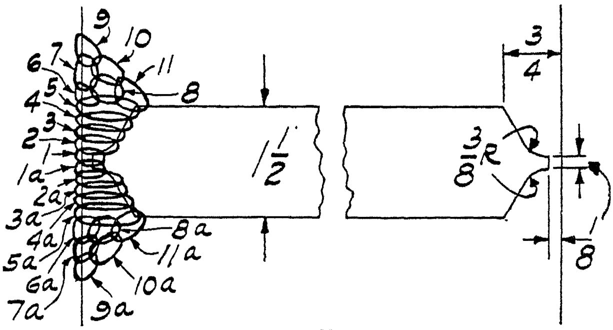


Fig. 216.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 215 1" plate	1-1a	5/32"	130	25		
	2-2a	1/4"	275	30		
	3-3a	5/16"	325	34		
	4-4a, 5-5a, 6-6a	1/4"	190	30	2.42	3.22
Fig. 216 1½" plate	1-1a	5/32"	130	25		
	2 to 4a inclusive	1/4"	275	30		
	5-5a	5/16"	325	34		
	6 to 11a inclusive	1/4"	190	30	1.00	7.04

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

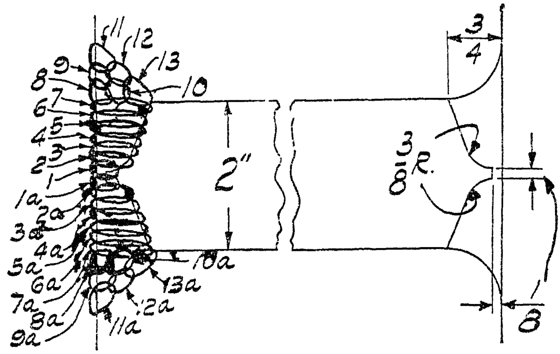


Fig. 217.

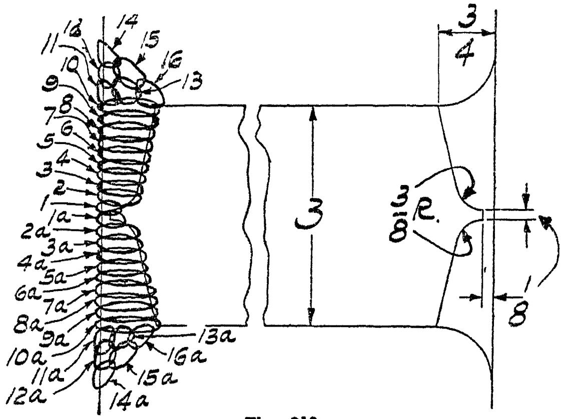


Fig. 218.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 217 2" plate	1-1a	5/32"	130	25		
	2 to 6a inclusive	1/4"	275	30		
	7-7a	5/16"	325	34		
	8 to 13a inclusive	1/4"	190	30	0.83	9.51
Fig. 218 3" plate	1-1a	5/32"	130	25		
	2 to 9a inclusive	1/4"	275	30		
	10-10a	5/16"	325	34		
	11 to 16a inclusive	1/4"	190	30	0.64	12.05

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Vertical Butt Welds. — General instructions as given in Page 144 including those for vertical welding, apply for making this type of welds.

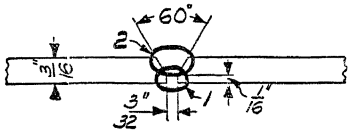


Fig. 219.

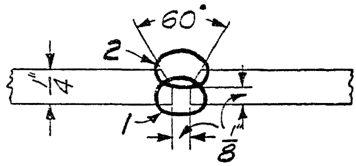


Fig. 220.

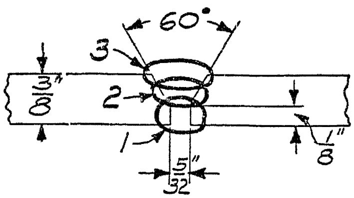


Fig. 221.

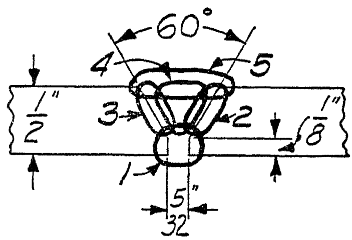


Fig. 222.

Welding Down.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 219 3/16" plate	1 2	1/8" 3/16"	110 150	25 25	25	.18
Fig. 220 1/4" plate	1 2	1/8" 3/16"	110 150	25 25	17.5	.29
Fig. 221 3/8" plate	3	3/16"	150	25	11	.44
Fig. 222 1/2" plate	5	3/16"	150	25	7	.72

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

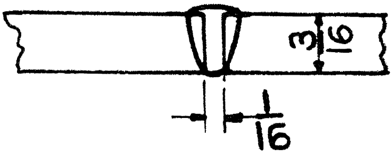


Fig. 223.

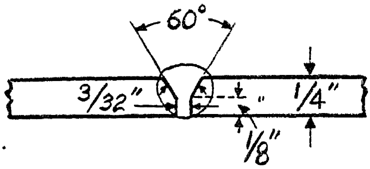


Fig. 224.

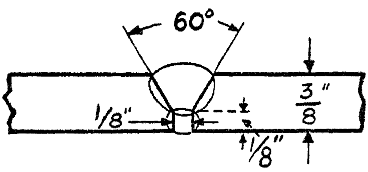


Fig. 225.

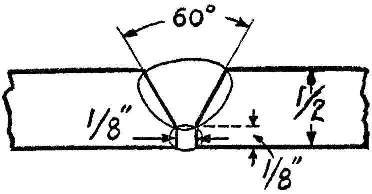


Fig. 226.

Welding Up.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 223 3/16" plate	1	1/8"	110	25	20	.15
Fig. 224 1/4" plate	1	1/8"	110	25	15	24
Fig. 225 3/8" plate	1 2	5/32" 5/32"	130 130	25 25	9.75	.44
Fig. 226 1/2" plate	1 2	5/32" 5/32"	130 130	25 25	5.25	.72

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Butt Welds, Overhead Position.—In general the same preparation, fit up and currents used in vertical welding apply to overhead welding with the exception the weld is generally made with a number of straight beads. However, weaving is sometimes accomplished by running small overlapping beads back and forth across the weld, the idea being to always keep the molten pool as small as possible. Extreme care must be taken to thoroughly clean all slag from bead before another is applied. If the mass of metal being welded is small so that it heats up considerably

during welding, allow it to cool between beads. For overhead butt welds a backing up strip is recommended. However, by butting the plates closer together overhead welding can be done without use of a backing up strip.

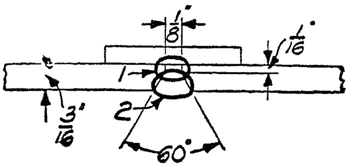


Fig. 227.

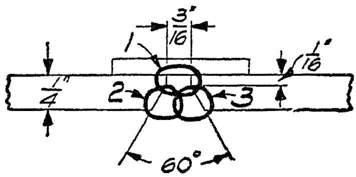


Fig. 228.

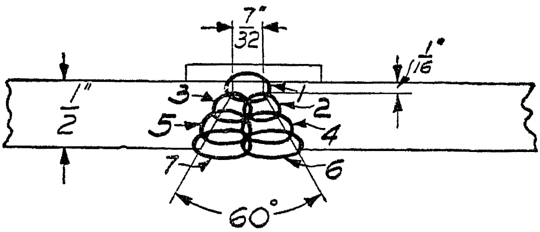


Fig. 229.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 227 3/16" plate	1 2	1/8" 3/16"	110 150	25 25	14	.33
Fig. 228 1/4" plate	1 2 3	1/8" 3/16" 3/16"	110 150 150	25 25 25	9	.45
3/8" plate Similar to Fig. 228	1 2 3 4	1/8" 5/32" 3/16" 3/16"	110 130 150 150	25 25 25 25	6	.70
Fig. 229 1/2" plate	1 2–3 4 to 7	1/8" 5/32" 3/16"	110 130 150	25 25 25	4	1.15

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Horizontal Welds.—Horizontal welds may be classified as Tee, Lap and Butt welds. The Tee weld is the same as a fillet weld (see Page 170 and following). The horizontal lap weld when the bead is made downward is essentially the same as a fillet weld, care being taken that metal at edge of lower plate is not allowed to run down. When the lap is made so electrode points upward, then the procedure is similar to lap and fillet overhead welds. (See Page 176.)

However, the butt weld is different. It falls in two classes as other welds, those not scarfed and those scarfed. When the plates are not scarfed, the maximum thickness for 100% fusion welding from both sides is about 3/16″.

A weaving motion of electrode, somewhat like a flattened circle with the loop toward top, is used so the bead has a good appearance and minimum tendency to flow low. A 1/8″, 5/32″ or 3/16″ electrode is used. This type of joint is rather infrequently used.

When the joint is scarfed, the procedure is something of a combination of vertical and fillet welding.

Two general types of scarfing may be used. One type has a 20° shelf or lower angle and 45° upper angle as shown in Figs. 230, 231, 232, and 233. This type of scarfing necessitates machining the plates somewhat differently and care is required in matching the plates in assembly. The following tabulation shows welding procedures and speeds for this type.

Fig. 230.

Fig. 231.

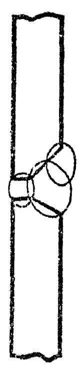


Fig. 232.

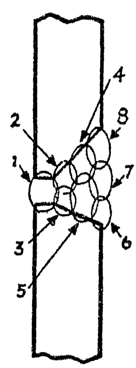


Fig. 233.

Type Joint 20°–45° Bevel	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 230 3/16" plate	2	5/32"	130	25	24	.16
Fig. 231 1/4" plate	2	5/32"	130	25	17.5	.23
Fig. 232 3/8" plate	3	5/32"	130	25	10.5	.38
Fig. 233 1/2" plate	8	5/32"	130	25	4.4	.86

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

The second type of scarfing is the usual 60° angle with two 30° angles as shown in Figs. 234 to 237. Although somewhat more difficult to weld than the 20°—45° scarfed joint, it is more frequently used due to greater simplicity of preparation for welding. Welding procedures and speeds for joints having 60° scarfing are given in the following table.

With either type of scarfing, welding is made easier by using a backing-up strip. In this case, the plates are spaced slightly farther apart than indicated in the sketches.

Type and Size of Joint (60° Bevel)	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 234 3/16" plate	2	5/32"	130	25	25	.15
Fig. 235 1/4" plate	2	5/32"	130	25	18	.22
Fig. 236 3/8" plate	3	5/32"	130	25	11	.37
Fig. 237* 1/2" plate	8	5/32"	130	25	4.6	.83

*Note: Sequence of 2 and 3. Sequence of 4 and 5 may be reversed. Fig. 237 as shown is recommended as being easier to tie-in overhead (2) than wash-in (3).

†Note: Speeds are actual welding time only and do not take into account other factors. See Page 142.

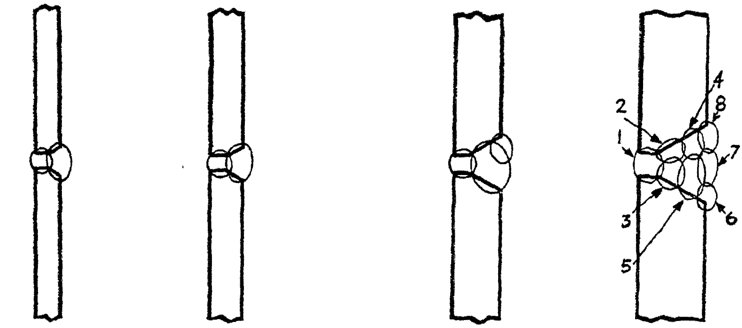


Fig. 234. Fig. 235. Fig. 236. Fig. 237.

Fillet Welds, Flat Position.—When making fillet welds in flat position the electrode should be held in the position indicated by the diagram, Fig. 238.

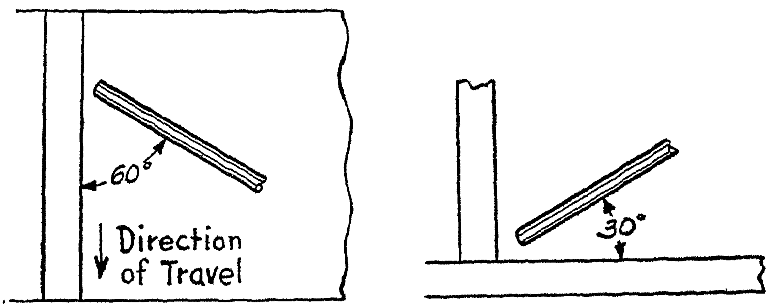


Fig. 238. Position of electrode for making fillet welds in flat position.

The angle formed by the electrode and horizontal plate should be approximately 30°; the electrode should also lean towards the direction of welding to form a 60° angle with the vertical plate. The path of the electrode should be in a straight line. The arc should be a trifle shorter than when making butt welds. It should be directed into the corner when both plates are of equal thickness. When this is not the case the arc should be directed slightly more on the plate of greater thickness so that both plates are heated to approximately the same temperature.

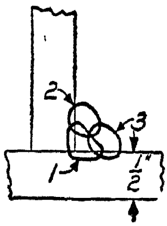


Fig. 239.

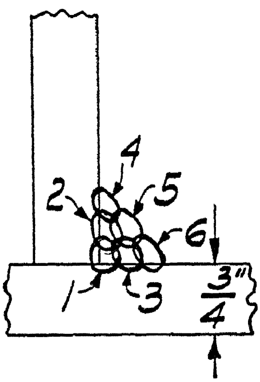


Fig. 240.

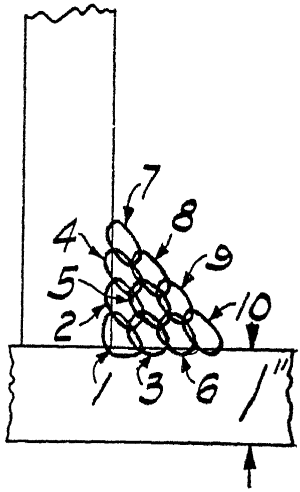


Fig. 241.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
3/16″ plate	1	1/4″	190	30	45	.155
1/4″ plate	1	1/4″	190	30	35	.20
3/8″ plate	1	1/4″	190	30	20	.37
Fig. 239 1/2″ plate	3	1/4″	190	30	10	.70
Fig. 240 3/4″ plate	6	1/4″	190	30	4	1.83
Fig. 241 1″ plate	10	1/4″	190	30	2.25	3.25

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Fillet Welds, Flat Position, Tilted.—When the work can be tilted, as shown in Fig. 242, so the molten pool of weld metal is horizontal, greatly increased welding speed can be obtained. For example, compare speed given in table below with speed of fillet welding horizontal joint of ½-inch plates.

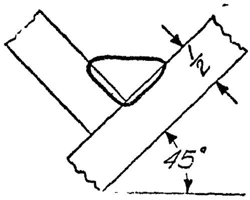


Fig. 242.

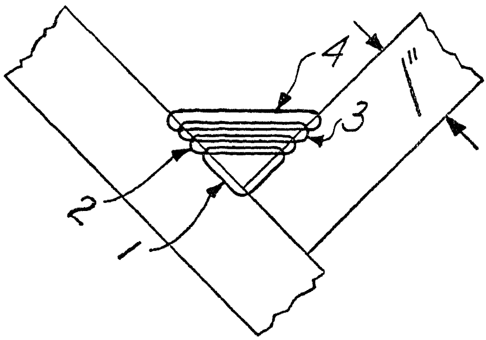


Fig. 243.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 242 ½" plate	1	⅜"	350	36	26	.63
¾" plate	1 2*	⅜" ⅜"	350 500	36 40	13½	1 46
Fig. 243 1" plate	1 2* 3* 4*	⅜" ⅜" ⅜" ⅜"	350 500 500 500	36 40 40 40	8	2.60

*Weave this bead.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Lap Welds.—There is little difference between lap welds and fillet welds with the exception of a closed joggled lap joint which requires a type of butt weld. For lap welds the work should be fitted up so that there is no appreciable gap between the plates to be welded. The electrode should be held as illustrated in Fig. 244. The arc should be played on the top corner of the upper plate and moved in a straight line.

Lap Welds, Flat Position.—Typical procedure and speeds are tabulated below for lap welds made when plates are in horizontal position.

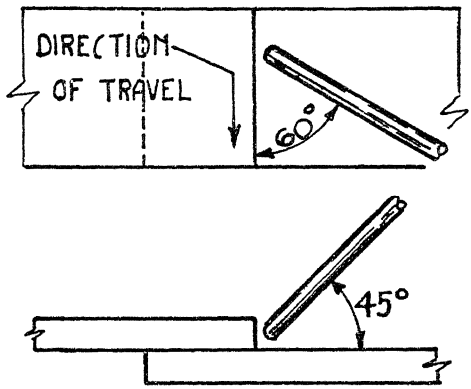


Fig. 244. Position of electrode for making lap welds.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
1/8" plate	1	1/4"	250*	30	100	.097
3/16" plate	1	1/4"	275	30	90	.120
1/4" plate	1	1/4"	250*	30	70	.138
5/16" plate	1	1/4"	250*	30	50	.19
3/8" plate	1	1/4"	250*	30	40	.237

*Note: An increase of current would cause difficulty due to tendency to burn through on 1/8" and to undercut top plate on 1/4" & thicker. 3/16" will permit increase current.

†Note: Speeds are actual welding time only and do not take into account other factors. See Page 142.

Lap Welds, Flat Position, Tilted.—When the work can be tilted so the molten pool of weld metal will be approximately horizontal, much higher welding speed can be obtained. Tilting of the plates

about 5 degrees will usually be sufficient to speed up the welding appreciably. Care should be taken however to avoid undercutting in the bottom plate.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
3/16" plate	1	5/16"	375	34	125	12
1/4" plate	1	5/16"	375	34	95	.160
3/8" plate	1	3/8"	425	38	70	.280

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

High Speed Lap Welds.—Lap welds are often made where water pressure tightness is not required. This type of weld may be limited in its application by appearance and quality and it may be porous with a joint efficiency of around 50%. Work must be fitted up without any appreciable gap. Short welds should be avoided.

Due to the higher currents used there may be a slight tendency towards increased warping. However, in most cases, this will be of little consequence.

A shorter arc should be used than for flat-position welds and due to the higher current, arc should not be held stationary at any point.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
3/16" plate	1	1/4"	500	30	200	.097
1/4" plate	1	5/16"	525	32	160	.130
5/16" plate	1	5/16"	550	36	140	.160
3/8" plate	1	3/8"	550	36	100	.25

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Lap and Fillet Welds, Vertical Position.—Vertical welding procedures, Page 145, apply for vertical lap and fillet welds. On plates up to 3/8″ the necessary beads can be woven one on top another as shown in Fig. 245. On plates 1/2″ and heavier it is recommended to place beads as shown in Fig. 246.

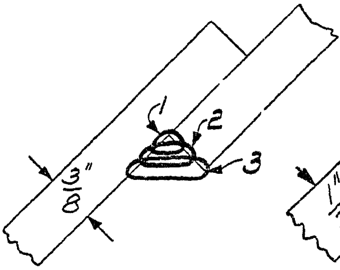


Fig. 245.

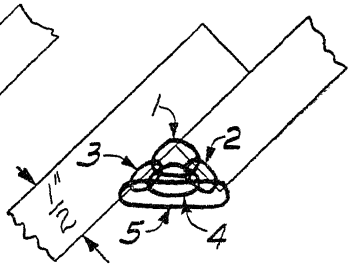


Fig. 246.

Welding Down.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
3/16″ plate	1	3/16″	150	25	35	.12
1/4″ plate	2	3/16″	150	25	19	.25
Fig. 245 3/8″ plate	3	3/16″	150	25	12	.40
Fig. 246 1/2″ plate	5	3/16″	150	25	6.5	.72
3/4″ plate	9	3/16″	150	25	3.25	1.5
1″ plate	14	3/16″	150	25	1.7	2.75

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Lap and Fillet Welds, Vertical Position.— Welding Up.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
3/16" plate	1	1/8"	110	25	18	.16
1/4" plate	1	5/32"	130	25	18	.23
3/8" plate	1	5/32"	130	25	9.5	.42
1/2" plate	2	5/32"	130	25	5	.72
1/2" plate	2	3/16"V	150	25	6.5	72
3/4" plate	3	3/16"V	150	25	3.25	1.45
1" plate	4	3/16"V	150	25	1.7	2.60

†Note: Speeds are for actual arc time only and do not take into account operating factor. See Page 142.

Lap and Fillet Welds, Overhead Position.—

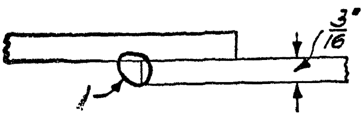


Fig. 247.

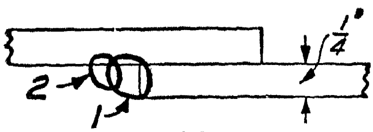


Fig. 248.

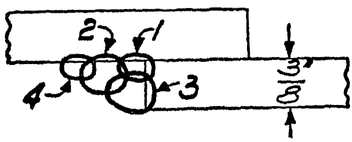


Fig. 249.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 247 3/16" plate	1	3/16"	150	25	35	.120
Fig. 248 1/4" plate	1 2	3/16" 1/8"	150 110	25 25	15	.26
Fig. 249 3/8" plate	1-2-3 4	3/16" 1/8"	150 110	25 25	9½	.53
1/2" plate Similar to Fig. 249	1 to 5	3/16"	150	25	6½	.75

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Edge Welds, Flat Position.—Edges should be fitted up close. The electrode to be held perpendicular and drawn along seam with arc only long enough to obtain a smooth rounded bead.

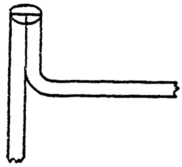


Fig. 250.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Ft. of Joint Per Hr.	Lbs. of Electrode Per Foot of Weld
⅛″	1	¼″	170	30	165	.030
3⁄16″	1	¼″	225	30	140	.062
¼″	1	5⁄16″	325	34	135	.097

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Plug Welds.—These are a special type of fillet welds made by fusing the metal of one plate to the side of a hole (generally round) in another plate, the plates being held closely together. Or there may be holes in both plates, and the sides of these holes fused together.

Specific types of plug welds are as follows:

(1) Round hole in one plate only. Here the diameter of the hole is from 1½ to 3 times the plate thickness, the larger value being used on the thinner plates. See Fig. 251.

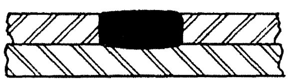


Fig. 251.

(2) Scarfed hole in one plate only. The scarfing corresponds to a backed-up butt joint with more than usual root opening as shown in Fig. 252.

Fig. 252.

(3) Round holes in both plates, as shown in Fig. 253.

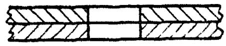


Fig. 253.

(4) Scarfed holes in both plates, as shown in Fig. 254.

Fig. 254.

Plug welds are used to advantage primarily in cases where access to the work is from one side only, (such as flooring, in cover plates for girders, additions to existing structures, or to provide additional strength or stiffness in cases where there is not sufficient space or accessibility available to use the usual fillet welds. An example of the latter case is a lap joint welded from one side only as shown in Fig. 255.

Fig. 255.

It is to be noted that plug welds cause practically no distortion and are therefore particularly useful in cases of plate fabrication, where distortion is encountered.

The procedure for plug welds is unique inasmuch as the direction of welding changes constantly. The corner must be completely fused. For any given instant the electrode position is standard, the usual 30°-60° slope. The electrode must be kept in proper position at all times, with speed of travel high enough to control the slag.

Use shielded arc electrodes at high currents. Bare electrodes are not satisfactory.

When both plates have holes, metal fillers are often used as shown in Fig. 256. Complete fusion must be attained, so the effect is the same as if all weld metal were deposited. The filler is an aid to speed, and ease of welding.

Fig. 256

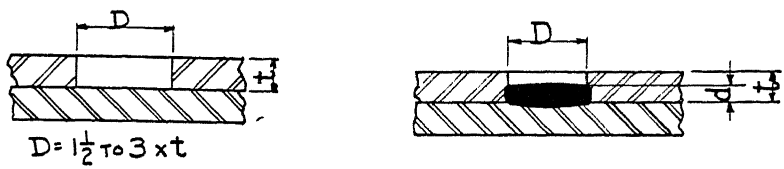


Fig. 257.

The following table will be of assistance in determining the size of plug welds to be used for various requirements.

PLUG WELDS (SEE FIG. 257)

Plate Thickness (t)	Dia. (D) Hole Inches	Depth (d) of Plug	Lbs. of Electrode per Plug (*)	Time per Plug — Seconds (†)	Design Load (lbs. sq. in) (††)
¼	¾	¼	.06	33	6,000
⅜	1	⅜	.14	76	10,700
½	1⅛	7/16	.23	125	13,500
⅝	1¼	½	.29	160	16,700
¾	1⅜	9/16	.46	250	20,200
1	1½	9/16	.53	290	24,000

*Based on 3/16" electrode—includes stub ends.
†Based on 3/16" electrode at 225 amps. (approx.).
No set-up fatigue, etc.
††Based on shear strength of 13,600 lbs./sq. in. on area of plug hole.
Note that the Design Load values given above are for one plug weld. Care must be taken that in combination with other plug welds or with other types of joints, they are fairly well spaced—and that the load distribution of the combination is taken into account.

TYPE A ELECTRODE WELDING OF SHEET METAL

Sheet metal, that is, metal of thicknesses up to approximately 8 ga., is used in a great many applications, such as duct lines of all kinds, for heating, ventilating and air conditioning, and for making package conveyors, hoppers, bins, door and window casings, kitchen equipment, parts of busses, fenders, fan housings, furnace casings, metal furniture, pans, trucks, etc.

As in other fields of manufacture, various factors determine the methods to be used in joining sheet metal together. The requirements are usually tightness, strength and appearance. Provided these conditions are satisfied to the required degree, then cost is the determining factor in selection of the method to use.

There are in general two types of joints used in joining sheet metal. These are: mechanical joints and welded joints. Mechanical joints may be divided into two classes: those soldered or those held

by some clamping device such as rivets; or mechanically locked joints. The riveted joint is a fairly strong one, and can be made tight, but under load conditions, as when subjected to corrosion, expansion, contraction and bending, the joint may easily develop leaks. The mechanically locked joint is an excellent one and is used to considerable extent. This type joint, if correctly made, is leakproof. However, this quality may be destroyed by operating conditions. It is evident that any load at right angles to the joint, such as might occur in a duct with pressure in it, has a tendency to open up the joint. In addition, corrosion may result. In some cases, the mechanically locked joint is soldered to obtain tightness.

The welded joint satisfies completely the requirements of a good joint. It is a complete fusing of the adjacent parts throughout the entire length of their contacting edges. The welded joint is strong, ductile, of good appearance, and low in cost.

In welding sheet metal, it is advisable to use some sort of jigs or fixtures to hold the parts in place for welding and take care of the stresses which are put into the metal during rolling and which are released during welding. These jigs or fixtures must be so designed to hold the parts in shape, without permitting them to warp. Copper clamps may be used. Care should be taken in regard to alignment and set up, and consideration in laying out a job should be given to methods of controlling expansion and contraction, (see Page 82). Good fit-up is imperative.

As in the case of any design, the selection of the type of joint to use in joining sheet metal is determined by the service conditions to be met. For example, a butt weld provides a smooth even surface at the joint. A lap weld, made in one bead only, has an opening or separation at the joint and substances may collect between the plates and cause corrosion.

Since both butt and lap joints are used extensively, it is evident that selection depends on the service to be met. It is obvious that the welded joint is tight, and the selection of the joint becomes a question of methods of welding and cost.

An electrode having low spatter and slag loss, depositing metal of high quality, should be used. The electrode should usually be negative and a short arc should be used since there is no tendency for electrode to stick. On thin sheets the generator must have proper current characteristics. These current characteristics are easily obtained with a welding generator designed for the work such as a 75 or 100 ampere unit. When welding with a higher capacity generator such as 300 ampere, it may be necessary, particularly on very thin sheets, to insert a resistance of approximately one ohm in series with the arc to reduce current to desired value.

In making vertical welds, welding either up or down may be used but downward is preferable.

Plain Butt Welds in Sheet Metal, Flat Position.—The requirements of weld are 100% penetration, 100% strength. Welds are made with no backing and are welded from one side only, see Figs. 258, 259, 260.

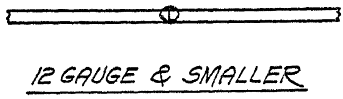


Fig. 258

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 258 20 ga.	1	3/32"	30*	18	110	.0132
18 ga.	1	3/32"	40*	18	120	.0149
16 ga.	1	1/8"	70*	29	130	.020
14 ga.	1	1/8"	85*	29	140	.026
12 ga.	1	5/32"	115	25	90	.038
Fig. 259 10 ga.	1	5/32"	135	25	80	.051
Fig. 260 8 ga.	1	3/16"V	190	27	80	.073

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

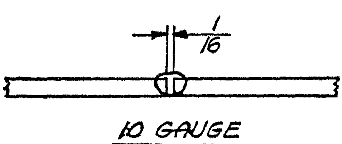


Fig. 259.

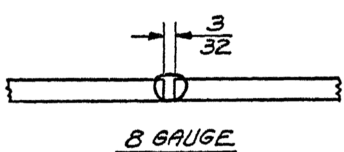


Fig. 260.

Vertical Butt Welds in Sheet Metal.—For 8-ga. and thinner sheets the work is fitted up as shown in Figs. 258, 259 and 260. Penetration will be 85% or better in 8-10-12-ga. sheets and 100% in 14-ga. and thinner.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 258 20 ga.	1	3/32"	30*	18	110	.0132
18 ga.	1	3/32"	40*	18	120	0149
16 ga.	1	1/8"	70*	29	130	020
Fig. 258 14 ga.	1	1/8"	80	29	120	026
Fig. 258 12 ga.	1	5/32"	110	26	85	.040
Fig. 259 10 ga.	1	5/32"	120	27	65	.053
Fig. 260 8 ga.	1	5/32"	130	27	50	.081

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Overhead Butt Welds in Sheet Metal.—The work is fitted up for welding as illustrated below for various thicknesses of material

Fig. 261.

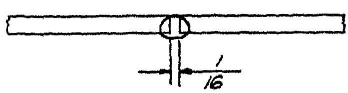


Fig. 262.

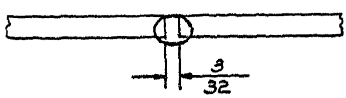


Fig. 263.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 261 20 ga.	1	3/32″	30*	18	110	.0132
18 ga.	1	3/32″	40*	18	120	.0149
16 ga.	1	1/8″	70*	29	130	.020
Fig. 261 14 ga.	1	1/8″	85*	29	140	.026
Fig. 261 12 ga.	1	5/32″	110	25	85	.040
Fig. 262 10 ga.	1	5/32″	115	25	65	055
Fig. 263 8 ga.	1	5/32″	120	26	45	.082

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Fillet Welds in Sheet Metal, Flat Position.—Instructions as to position the electrode should be held in for making fillet welds are given in Fig. 238.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
18 ga.	1	3/32″	40*	21	60	.031
16 ga.	1	1/8″	70*	27	60	042
14 ga.	1	1/8″	100	25	60	.060
12 ga.	1	5/32″	150	25	60	.074
10 ga.	1	3/16″V	160	25	60	.081
8 ga.	1	3/16″V	160	25	50	.103

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Lap Welds in Sheet Metal, Flat Position.—Typical procedure and speeds are tabulated below for lap welds made when plates are in horizontal position. (See Fig. 244.)

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
20 ga.	1	3/32"	40*	21	100	.020
18 ga.	1	3/32"	60*	22	100	.023
16 ga.	1	1/8"	100	25	100	.029
14 ga.	1	5/32"	130	25	100	.037
12 ga.	1	5/32"	135	25	90	.045
10 ga.	1	3/16"	155	28	90	.075
8 ga.	1	3/16"	165	28	90	.091

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Vertical Lap Welds in Sheet Metal.—General procedures for vertical welding, see Page 144, apply for this type of weld.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
20 ga.	1	3/32"	40*	21	100	.020
18 ga.	1	3/32"	60*	22	100	.023
16 ga.	1	1/8"	100	25	100	.029
14 ga.	1	5/32"	130	25	100	.037
12 ga.	1	5/32"	120	26	75	.049
10 ga.	1	3/16"	130	26	90	.062
8 ga.	1	3/16"	140	26	65	.073

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Vertical Fillet Welds in Sheet Metal.—General procedures for vertical welding, see Page 144, apply for this type of weld.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
18 ga.	1	3/32"	40*	21	60	.031
16 ga.	1	1/8"	70*	27	60	.042
14 ga.	1	1/8"	90	24	60	.047
12 ga.	1	5/32"	140	24	60	.071
10 ga.	1	5/32"	150	24	55	.081
8 ga.	1	5/32"	160	24	50	.107

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Overhead Lap Welds in Sheet Metal.—This type of weld in sheet metal is made with one bead as shown in Fig. 247.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
20 ga.	1	3/32"	40*	21	100	.020
18 ga.	1	3/32"	60*	22	100	.023
16 ga.	1	1/8"	100	25	100	.029
14 ga.	1	5/32"	130	25	100	.037
12 ga.	1	5/32"	120	25	65	.051
10 ga.	1	5/32"	120	25	60	.058
8 ga.	1	5/32"	120	25	55	.064

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Overhead Fillet Welds in Sheet Metal.—

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
18 ga.	1	3/32"	40*	21	60	.031
16 ga.	1	1/8"	70*	27	60	042
14 ga.	1	1/8"	85	24	50	.054
12 ga.	1	5/32"	120	24	50	.072
10 ga.	1	5/32"	130	24	50	.078
8 ga.	1	5/32"	130	24		

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

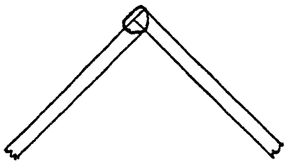
†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Corner Welds, Flat Position, in Sheet Metal.—For welds of this type in 12 ga. and thinner material the work should be fitted up as shown in Fig. 264; for 10 ga., see Fig. 265; for 8 ga., see Fig. 266. Procedures for making corner welds in heavier material are the same as given for fillet welds, see Page 170.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 264 20 ga.	1	3/32"	40*	21	180	.0104
18 ga.	1	3/32"	60*	24	180	.0140
16 ga.	1	1/8"	90*	24	160	.020
Fig. 264 14 ga.	1	1/8"	90	24	120	.022
Fig. 264 12 ga.	1	3/16",V	125	24	100	.037
Fig. 265 10 ga.	1	3/16",V	140	24	90	.042
Fig. 266 8 ga.	1	3/16",V	175	27	80	.065

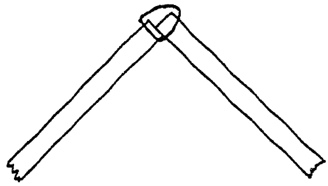
*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.



12 GAUGE & SMALLER

Fig. 264.



10 GAUGE

Fig. 265.

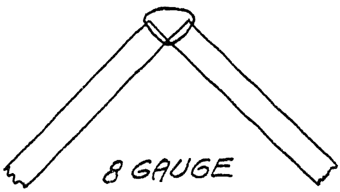


Fig. 266.

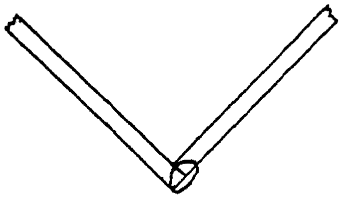
Vertical Corner Welds in Sheet Metal.—Work should be prepared in the same manner as prescribed for making corner welds in flat position, see Figs. 264, 265, 266. Procedures for making this type weld in heavier material are the same as given for lap and fillet welds, vertical position, Page 175.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 264 20 ga.	1	3/32"	40*	21	180	.0104
18 ga.	1	3/32"	60*	24	180	.0140
16 ga.	1	1/8"	90*	24	160	.020
Fig. 264 14 ga.	1	1/8"	80	28	100	.022
Fig. 264 12 ga.	1	5/32"	110	28	95	.036
Fig. 265 10 ga.	1	5/32"	130	28	90	.043
Fig. 266 8 ga.	1	5/32"	130	28	75	.051

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

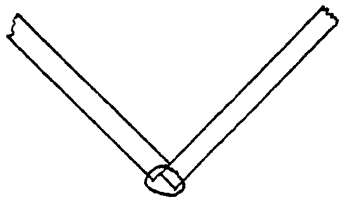
†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

Overhead Corner Welds in Sheet Metal.—Fig. 267 illustrates fit up of work for 12-ga. and thinner material. For 10-ga. see Fig. 268; for 8-ga. see Fig. 269. Heavier material is welded in the same manner as prescribed for overhead lap and fillet welds, see Page 176.



12 GAUGE & THINNER

Fig. 267.



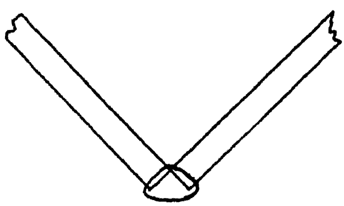
10 GAUGE

Fig. 268.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 267 20 ga.	1	3/32″	40*	21	180	.0104
18 ga.	1	3/32″	60*	24	180	.0140
16 ga.	1	1/8″	90*	24	160	.020
Fig. 267 14 ga.	1	1/8″	75	25	95	.024
Fig. 267 12 ga.	1	5/32″	110	26	95	.039
Fig. 268 10 ga.	1	5/32″	125	26	90	042
Fig. 269 8 ga.	1	5/32″	125	26	65	058

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account operating factors. See Page 142.



8 GAUGE

Fig. 269.

Edge Welds in Sheet Metal, Flat Position.—Edges should be fitted up close. The electrode to be held perpendicular and drawn along seam with arc only long enough to obtain a smooth rounded bead

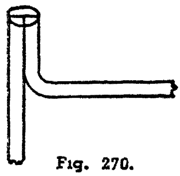


Fig. 270.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
20 ga.	1	3/32″	40*	21	200	.0094
18 ga.	1	3/32″	60*	23	200	0126
16 ga.	1	1/8″	80*	25	180	.0171
14 ga	1	1/8″	110	27	175	018
12 ga.	1	3/16″	145	28	160	.023
10 ga.	1	3/16″	150	28	135	.029
8 ga.	1	3/16″	160	28	125	.031

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account operating factors. See Page 142.

Vertical Edge Welds in Sheet Metal.—

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
20 ga.	1	3/32″	40*	21	200	.0094
18 ga.	1	3/32″	60*	23	200	.0126
16 ga.	1	1/8″	80*	25	180	0171
14 ga	1	1/8″	80	26	120	.019
12 ga.	1	5/32″	110	26	110	.023
10 ga.	1	5/32″	120	27	100	.029
8 ga.	1	5/32″	120	27	80	.033

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal

†Note: Speeds are for actual arc time only and do not take into account operating factors. See Page 142.

Overhead Edge Welds in Sheet Metal.—

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	†Arc Speed, Foot Per Hr.	Lbs. of Electrode Per Foot of Weld
20 ga.	1	3/32″	40*	21	200	.0094
18 ga.	1	3/32″	60*	23	200	.0126
16 ga.	1	1/8″	80*	25	180	0171
14 ga.	1	1/8″	80	26	120	.019
12 ga.	1	5/32″	110	26	110	.023
10 ga.	1	5/32″	120	26	100	.029
8 ga.	1	5/32″	120	27	80	.033

*Electrode, Negative; Work, Positive. Electrode especially designed for sheet metal.

†Note: Speeds are for actual arc time only and do not take into account other factors. See Page 142.

TYPE A ELECTRODE FOR HIGH TENSILE STEEL

The following procedures, Pages 190 to 192, are for a well known Type A electrode of the flat-bead characteristics used in the welding of low-alloy, high tensile steel, and giving a weld of approximately 75,000 pounds per square inch. Classification, American Welding Society Filler Metal Specifications, E7010.

General.—Use reversed polarity (work negative, electrode positive). Clean each bead thoroughly before applying next bead. To eliminate craters at end of weld or when changing electrodes, withdraw electrode slowly until arc is broken.

Flat Welding.—A somewhat longer arc is required than that used with bare or lightly coated electrode. Hold arc so that arc voltage is not less than 30 volts. The distance from the end of the coating to the work should not be less than 1/8″. Do not allow the coating to dip down into the molten metal.

The amperage used with a particular size of electrode will vary with the thickness of plate, type of joint, position of welding, fit-up, etc. The minimum and maximum currents for the various sizes are given below:

Electrode Size	Amperage Range	
	Min.	Max.
1/8″	75	130
5/32″	90	175
3/16″	140	225
1/4″	190	325
5/16″	250	400

Vertical and Overhead Welding.—In vertical welding start at the bottom of the weld, build up a shelf, weaving from side to side the full width of the weld or vee.

Use 5/32" for most work. 3/16" can be used for finish beads and on heavy plate. Arc voltage should not be less than 25 volts.

In overhead welding, hold the electrode vertical and oscillate the arc slightly. In welding thick plate, make the weld with several narrow beads. Do not weave a wide bead the full width of the V. Clean each bead thoroughly before applying the next.

Electrode Size	Amperage Range	
	Min.	Max.
1/8"	75	130
5/32"	100	160
3/16"	125	180

In general, use currents about in middle of above ranges.

As mentioned on Page 150, there is another Type A electrode (flat bead) which gives a higher tensile strength than the E7010. Following is a procedure for a well known electrode of this type which gives a weld of 95,000 to 105,000 lbs. per sq. in. tensile strength.

General.—Use reversed polarity (work negative, electrode positive). Clean each bead thoroughly before applying next bead. To eliminate craters at end of weld or when changing electrodes, withdraw electrode slowly until arc is broken. Hold a fairly short arc (24 – 28 volts) but do not allow the coating to dip into molten metal.

Flat Welding.—The amperage used with a particular size of electrode will vary with the thickness of plate, type of joint, position of welding, fit-up, etc. The minimum and maximum values for the various sizes are given below.

Electrode Size	Amperage Range	
	Min.	Max.
1/8"	70	120
5/32"	90	170
3/16"	125	210

In general, amperage in the middle of above ranges will be found most satisfactory for flat work.

Vertical and Overhead Welding.—Use 5/32" for most work. The 3/16" size can be used for finish beads and on heavy plate.

In vertical welding start at the bottom of the weld, build up a shelf, weaving from side to side the full width of the weld or vee.

In overhead welding, hold the electrode vertical and oscillate the arc slightly. In welding thick plate, make the weld with several narrow beads. Do not weave a wide bead the full width of the vee. Clean each bead thoroughly before applying the next.

In general, use currents slightly under the middle of the above ranges.

PROCEDURES FOR TYPE B ELECTRODES (CONVEX BEAD)

The following procedures on Pages 192 to 198, apply to a well-known Type B electrode of convex bead characteristics (American Welding Society Specifications E6012).

Polarity: Straight (electrode negative, work positive). Also operates well with A.C.

Arc Length: Hold as short an arc as practical similar to bare electrode welding. (See approximate arc voltage below.)

Current: Because of variations in thickness of plate, fit-up, etc., specific current values vary, however, the following table will give the usable amperage ranges and arc voltage for the various sizes of electrodes. A recommended current value is also given which is the approximate current used on most jobs.

Size	Amperage			Arc Voltage
	Min.	Max.	Recommended	
3/32″	25	90	70	16 - 20
1/8″	55	140	115	20 - 24
5/32″	90	200	150	21 - 25
3/16″	120	275	210	22 - 26
7/32″	140	325	255	23 - 27
1/4″	175	500	300	24 - 28
5/16″	240	625	380	26 - 30
3/8″	300	750	450	28 - 32

The following procedure is for fit-ups as shown. Unless dimensions are shown, joints are fitted tight. No allowance is made for fatigue, change of electrodes, etc.

Note that while the data are for good fit-up this is particularly applicable to work where fit-up is not very good. It builds up easily and consequently high speeds may be attained with easy operation on relatively poor fit-ups. See Page 150.

Note however that in some cases, as lap joints of thin material and poor fit-up, care must be taken to make sure that no slag gets in along the side or edge of upper sheet adjacent to the weld. Attention should be given to fit-up in this particular case to get good results at reasonable speeds.

It is obvious that due to the characteristics of the deposit, i.e., it piles up, vertical and overhead beads may not be as smooth as deposits from a Type A electrode.

In the following, speeds are given without any allowance for fatigue or fit-up. Pounds per foot of electrode include stub end losses.

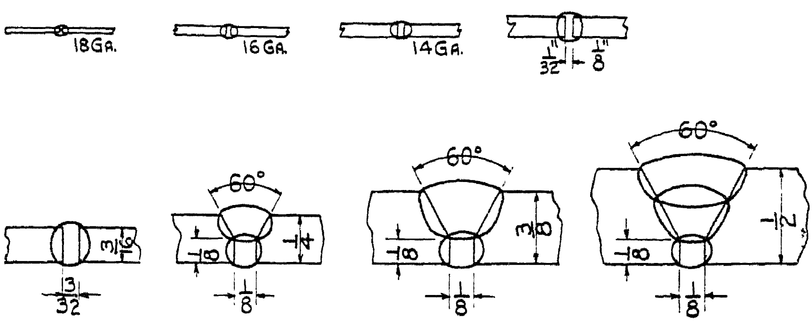


Fig. 271.

Butt Welds—Without Backing

Joint See Fig. 271	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
18 ga.	1	3/32″	70	19	110	.019
16 ga.	1	1/8″	100	21	110	.023
14 ga.	1	1/8″	120	23	110	.030
1/8″	1	5/32″	150	23	80	.0530
3/16″	1	3/16″	215	24	55	.120
1/4″	1	5/32″	150	22	19	.36
	2	1/4″	275	24		
3/8″	1	5/32″	150	22	15	.53
	2 (weave)	1/4″	300	24		
1/2″	1	5/32″	150	22	11	.95
	2	1/4″	300	24		
	3 (weave)	5/16″	375	25		

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

Fillet Welds—

Where heavier joints are made, proceed as indicated and use last size electrode for a sufficient number of passes to complete joint.

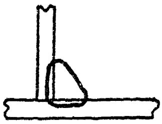


Fig. 272.

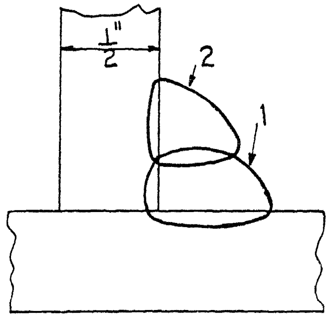


Fig. 273.

FILLET WELDS

Joint See Fig. 272	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
18 ga.	1	3/32"	75	19	65	.031
16 ga.	1	1/8"	100	21	65	.041
14 ga.	1	1/8"	120	22	65	.048
1/8"	1	3/16"	200	23	80	.080
3/16"	1	1/4"	275	25	65	.140
1/4"	1	1/4"	300	27	50	20
5/16"	1	5/16"	350	28	45	.29
3/8"	1	5/16"	375	28	35	.40
Fig. 273 1/2"	1	5/16"	350	28	17	.80
	2	5/16"	350	28		

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

Lap Welds—

Play arc on bottom plate and govern travel so that upper edge just melts and fills in properly.

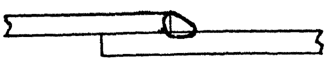


Fig. 274.

LAP WELDS

Joint See Fig. 274	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
18 ga.	1	3/32"	75	19	75	.028
16 ga.	1	1/8"	100	21	75	038
14 ga.	1	1/8"	120	22	75	044
1/8"	1	3/16"	200	23	100	060
3/16"	1	1/4"	275	24	90	106
1/4"	1	1/4"	300	25	65	160
5/16"	1	1/4"	300	25	45	.234
3/8"	1	1/4"	300	25	35	.298

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

Corner Welds—

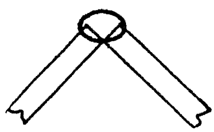


Fig. 275.

CORNER WELDS

Joint See Fig. 275	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
18 ga.	1	3/32"	70	19	125	.0140
16 ga.	1	1/8"	110	21	125	.0250
14 ga.	1	1/8"	125	22	125	.0290
1/8"	1	5/32"	170	24	125	.039
3/16"	1	3/16"	215	25	65	.113
1/4"	1	1/4"	300	27	55	.189
3/8"	1	5/16"	375	28	40	.37

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

Edge Welds—

Fig. 276.

EDGE WELDS

Joint See Fig. 276	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
18 ga.	1	3/32"	75	19	140	.0140
16 ga.	1	1/8"	100	21	140	.021
14 ga.	1	5/32"	150	20	140	.031
1/8"	1	3/16"	215	22	115	.055
3/16"	1	1/4"	300	22	105	.086
1/4"	1 (slight weave)	5/16"	350	24	85	.140

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

Vertical and Overhead Welding—

In making vertical welds, welding from the bottom up is generally recommended, however, on thin material where a very small bead is desired, welding may be downward.

Sizes of 1/8" and 5/32" generally are recommended for vertical and overhead work, although on thicker plates the 3/16" size may be used to advantage.

VERTICAL FILLET AND LAP WELDS

Joint Figs. 272-274	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
3/16" down	1	5/32"	150	22	40	110
1/4" down	2	5/32"	150	22	19	.23
3/8" up	1	5/32"	150	22	9.5	.45
1/2" up	2	5/32"	150	22	5	.86
3/4" up	2	5/32"	150	22	3.00	1 66
	1	3/16"	215	23		

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

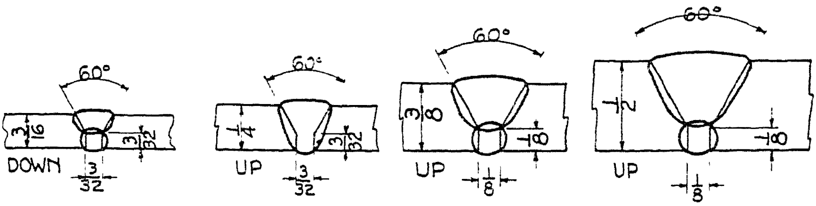


Fig. 277.

VERTICAL BUTT WELDS

Joint See Fig. 277	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
3/16″	1	1/8″	115	20	18	.18
	2	5/32″	150	22		
1/4″	1	1/8″	115	20	10	.27
3/8″	2	5/32″	150	22	8	.56
1/2″	2	5/32″	150	22	5	.86

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

In all cases of butt welds, backing up strip is beneficial and where **practical should be used.**

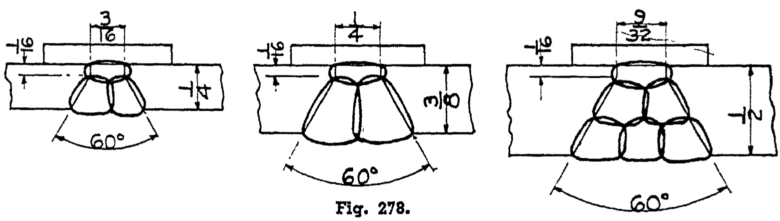


Fig. 278.

OVERHEAD BUTT WELDS

Joint See Fig. 278	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
1/4″	1	1/8″	125	19	10.5	.391
	2	5/32″	150	21		
3/8″	1	1/8″	125	19	6.5	.62
	2	5/32″	150	21		
1/2″	1	1/8″	125	19	4.0	1.00
	2	5/32″	150	21		

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

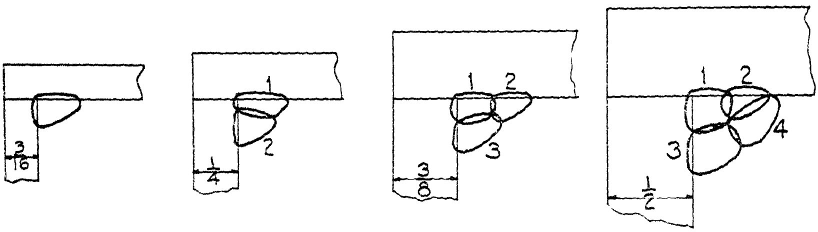


Fig. 279.

OVERHEAD FILLET AND LAP WELDS

Joint See Fig. 279	Beads or Passes	Electrode Size	Amps.	Volts	Arc Speed Ft. of Joint Per Hr.	Lbs. of Electrode per Ft. of Weld
3/16"	1	5/32"	150	21	35	.130
1/4"	2	5/32"	150	21	16.5	.28
3/8"	3	5/32"	150	21	9.0	.54
1/2"	5	5/32"	150	21	4.5	1.03

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

PROCEDURES FOR TYPE C ELECTRODES (CONCAVE BEADS)

For Fillet Welding

The following procedures are for a well known mild steel Type C electrode of concave bead characteristics. American Welding Society Specifications, E6020, for fillet welding in the down or flat position.

General.—This electrode operates with either AC or DC. If DC is used, the electrode should be run with straight (negative) polarity, (work positive). Approximate current ranges for fillet welds with one plate vertical are as follows:

Electrode Size	Amperage Range			Arc Voltage	
	Min.	Max. 1 Plate Vertical	Max. *	Min.	Max.
5/32"	80	160	180	20	24
3/16"	130	225	250	21	26
1/4"	225	300	375	24	30
*5/16"	325		500	26	34
*3/8"	425		625	28	38

* Work positioned.

The exact current for best results will depend on thickness of plate, fitup and size of bead desired.

If the plates are tilted so that the welding is done in the flat position, the maximum currents may be increased to approximately the values given under maximum.

Success in making smooth fillet welds with equal legs and without undercutting or overlapping depends upon several factors which must be controlled in the welding operation.

1. Arc Blow.—Either a strong forward or backward magnetic arc blow will prevent the making of a first class fillet weld. With AC, little difficulty will be experienced with arc blow. With DC, the well known methods such as placing the ground to counteract blow, should be employed.

2. Arc Length.—Hold a close arc. The coating should not touch the molten metal, but should be held as closely as possible. This is particularly important in making large single pass fillets where one plate is vertical. Too long an arc will cause undercutting at the vertical plate. Too much current will cause the same difficulty. If small fillets and speedy welding are desired, the coating can be dragged against the plates.

3. In general, the electrode should be pointed backward at any angle of about 60 degrees to the line of the weld as this assists in getting proper slag coverage of the bead and helps to keep the slag from running ahead of the arc.

4. Perhaps the most important thing to watch in obtaining a uniform bead is to control the current and rate of welding so that the slag freezes over the entire surface of the bead. With a given thickness of plate and a given current, too fast a rate of travel may cause the slag to form in islands which results in a rough bead. On the other hand, too slow a rate of travel may cause so much slag to be piled up that it will run down away from the vertical plate and spoil the contour of the bead.

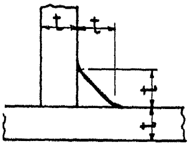


Fig. 280. Flat position.

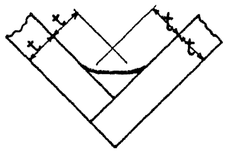


Fig. 281. Flat, tilted position.

Note: Welds larger than 3/8" should be made with multiple stringer passes using 3/16" electrode at 200 amps. Beads as actually deposited may be larger than nominal size "t," particularly in smaller sizes.

It is to be noted that the following procedure is conservative, and that in the heavier joints (above 1/4") the superiority of this type electrode is most evident.

Joint "t"	Remarks (See Fig. 280 and Fig. 281)	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed Ft. of Joint Per Hr.	Electrode LBS/FT of Weld
3/16"	Flat	1	3/16	200	21	43	16
	Tilted	1	3/16	250	21	53	16
1/4"	Flat	1	1/4	250	24	40	.25
	Tilted	1	1/4	350	24	53	25
3/8"	Flat	1	1/4	300	24	30	39
	Tilted	1	5/16	500	26	48	39
1/2"	Tilted	1	5/16	500	26	34	.55
3/4"		1	5/16	500	26		
	Tilted	2	3/8	600	28	16	1 32
		1	5/16	500	26		
1"	Tilted	2	3/8	600	28		
	Slight weave	3	3/8	600	28	10	2.25

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

TYPE C ELECTRODE FOR DEEP-GROOVE WELDING

The following procedures are for a well known mild steel Type C electrode of concave bead characteristics, designed particularly for "U" groove joints in flat position. American Welding Society Specifications E6030. Included with these procedures is also the procedure for the finish pass or last pass electrode mentioned and discussed on Page 152.

These electrodes are designed to operate with either A. C. or D. C. With D. C. they will operate equally well with positive or negative polarity.

When D.C. is used, positive polarity is generally recommended. However, there are certain conditions frequently encountered in deep-groove welding which tend to cause the formation of surface holes in the weld metal. When welding steels containing more than normal amounts of manganese, silicon, aluminum or slag segregations high in sulphur, or phosphorus, surface holes are quite often encountered, especially in the first few beads of a deep-groove weld. Under these conditions, the use of negative polarity will generally eliminate the surface holes.

Therefore, when D. C. is used, it probably will be necessary if best results are to be obtained, to start at the bottom of a deep groove with negative polarity and change to positive polarity after the first few beads have been deposited.

It should be mentioned that small surface holes, as a result of excessively deoxidizing atmosphere at bottom half of groove, are remelted in depositing subsequent beads and do not appear in the finished weld.

The usual practice should be followed in cleaning off the slag (which comes off very easily) before the next bead is deposited.

Hold a fairly close arc, but do not allow the coating to touch the molten metal.

The following table may be used as a guide in selecting the best welding currents for a given job.

Electrode Size	Amperage Range			Arc Voltage		
	Min.	Av.	Max.	Min.	Av.	Max.
3/16″	175	220	250	24	28	30
1/4″	275	330	375	29	34	37
5/16″	375	425	500	34	40	44

Values near those in the "average" column will be found best for welds of highest quality.

General Procedure.—Depending upon local shop conditions various first pass procedures can be used. In general, required quality of weld and fit-up will govern the procedure to be followed.

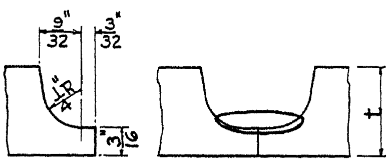


Fig. 282.

Procedure for the joint shown in Fig. 282 calls for edges butted tightly together. 3/16″ Type C electrode should be used.

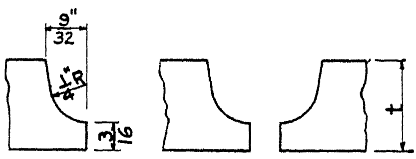


Fig. 283.

Procedure for the joint shown in Fig. 283 calls for edges to be spaced 5/32″ to 3/16″. 5/32″ Type A electrode or 3/16″ Type B electrode should be used.

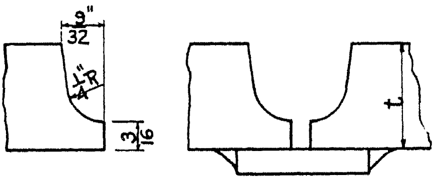


Fig. 284.

Procedure for the joint shown in Fig. 284 calls for the edges to be spaced any amount depending upon required overall dimension.

With a steel backing-up strip tacked to the under side of the joint, a ¼" Type C electrode should be used.

In general the procedures, after the first pass, will be identical. It is self evident that when the size of the groove is larger than recommended the required amount of electrode per foot of weld will be higher and the arc speed somewhat lower (see Page 208 discussing effect of wide groove and fit-up on cost). It is recommended to change from layer passes to overlapping passes whenever the bead width exceeds ¾".

In order to meet certain specifications, it may be required to chip out pass (1) to the point where clean sound metal is reached. This back-groove is then filled similar to pass (2).

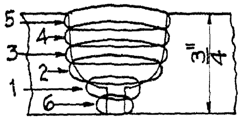


Fig. 285.

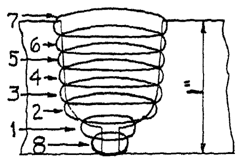


Fig. 286.

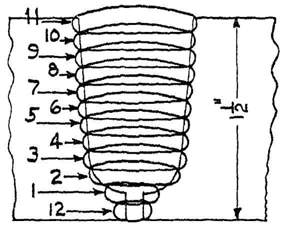


Fig. 287.

Joint "t"	Beads or Passes	Electrode Size	Amperage	Min. Arc Volts	Arc Speed Ft. of Joint Per Hr.	Electrode LBS/FT of Weld	Remarks
	1	3/16	220	24			
	2	¼	340	29			
Fig. 285	3	¼	340	29			
	4	¼	340	29			
	5	¼	300	29			Finish
	6	¼	340	29	7.5	1.9	
	1	3/16	220	24			
	2	¼	340	29			
	3	¼	340	29			
Fig. 286	4	¼	340	29			
	5	¼	340	29			
	6	¼	340	29			
	7	¼	300	29			Finish
	8	¼	340	29	4.75	2.9	
	1	3/16	220	24			
	2	¼	340	29			
	3	¼	340	29			
	4	¼	340	29			
	5	¼	340	29			
Fig. 287	6	¼	340	29			
	7	¼	340	29			
	8	¼	340	29			
	9	¼	340	29			
	10	¼	340	29			
	11	¼	300	29			Finish
	12	¼	340	29	3.25	4.2	

Note: Speeds are actual arc time only and do not take into account other factors. See Page 142.

TYPE C ELECTRODE FOR FINISH PASS WELDING

An electrode designed for down-hand welding on flat surfaces for finish bead welding and to provide full slag coverage and exceptional smoothness, is frequently used in combination with the electrode discussed above. Following are the recommended procedures.

Electrode Size	Amperage Range	
	Min.	Max.
¼″ x 18″	275	400
5/16″ x 18″	325	600

Lower currents are for lighter plates where heat capacity is low. Higher currents are for heavy plates.

It can be used with either normal or reverse polarity D. C. or with A. C. current.

Hold a fairly close arc, but take care not to allow coating to touch the molten metal.

This may be used for finish bead on both sides as the final bead upon completion of the joint then number one bead may be chipped out and a pass made similar to bead number two. This is followed by a finish bead.

TYPE C ELECTRODE FOR HIGH TENSILE STEELS

The following procedures are for a well known high tensile Type C electrode of concave bead characteristics, designed for flat "U" groove welding, and generally used for the low-alloy high-tensile steels. American Welding Society Filler Metal Specifications E7030.

General Instructions.—Polarity: This electrode is designed to operate with either A. C. or D. C. With D. C. it will operate equally well with positive or negative polarity. When D. C. is used, positive polarity is generally recommended.

The usual practice should be followed in cleaning off the slag (which comes off very easily) before the next bead is deposited.

Hold a fairly close arc, but do not allow the coating to touch the molten metal.

The following may be used as a guide in selecting the proper welding currents for a given job.

Electrode Size	Amperage Range	
	Min.	Max.
3/16″	180	230
¼″	300	360

The general practice of preheating high tensile plate to 300° F. and keeping the work at that temperature throughout the welding operation, is highly recommended.

The detailed procedure for using this type electrode will be very similar to that given for E6030 requirements.

TYPE C ELECTRODE FOR A. C. WELDING

The following procedures are for a well known Type C electrode of concave bead, designed especially for use with A. C. American Welding Society Specifications E6013.

Electrode Size	Amperage Range	
	Min.	Max.
3/32" x 12"	25	85
1/8" x 14"	45	135
5/32" x 14"	65	190

It will be noticed that a wide range of current is given for each size. The low currents are minimum, used to make a weld on light gauge metal. The maximum values are for rapid deposition and high-speed welding on plate that is heavy enough to take the heat. For most work, amperage near the middle of the range should be used.

Hold a fairly close arc.

When making vertical welds, welding upward is recommended, using current values near the middle of the range.

INTERPOLATING DATA ON IN-BETWEEN SIZES OF PLATE

Occasionally, it may be necessary to have information on sizes of joints not shown definitely in tabular form. One of the quickest and easiest ways to get this is to plot curves and from these take the data.

For example, suppose information is desired on the welding of 5/16" and 7/16" plates with V groove butt joints, flat position. Refer to the table on Page 155. Plot horizontally to an enlarged scale the plate thicknesses as shown in Fig. 288.

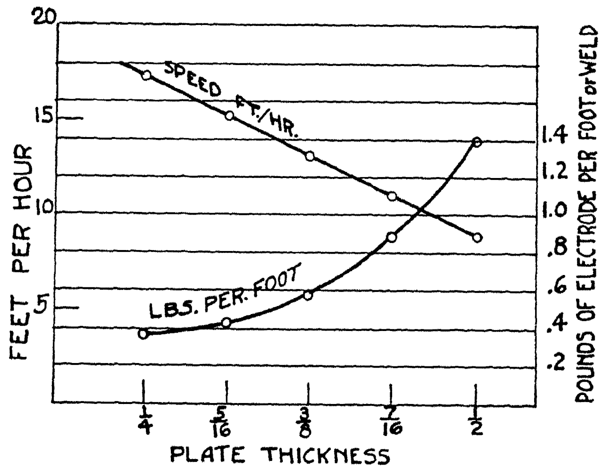


Fig. 288.

Against these plot the speed and pounds of electrode required per foot of weld.

At the desired plate thicknesses measure the values desired. For example,

at 5/16″—.45 lbs. per foot at 15.2 ft. per hr.
at 7/16″—.93 lbs. per foot at 11 ft. per hr.

The electrode size, amperes and voltage may be judged from the tabulation. The first bead is the same in all cases, and for 7/16″ plate use 1/2″ data. For 5/16″ plate use 3/8″ data.

ESTIMATING WELDING COSTS FOR THE MANUAL SHIELDED ARC PROCESS

Factors Involved.—The real cost of a product must include not only the expenditure of time, money and materials for direct manufacturing, but must also take into account the service life and performance. The importance of these factors dictates that they must be kept in mind at all times from the inception of the design to its final completion and use in service.

Production costs of a welded item may be divided into three general parts, namely,

(1) Preparation
(2) Welding
(3) Finishing Treatment

Preparation involves design; forming, cutting and welding; selection of the type of joint fitup; sub assembly, and final assembly.

Design.—Preceding actual fabrication—even before pencil is put to paper—the design must be carefully analyzed and visualized so that its fabrication in relation to the equipment and facilities available in the plant wherein it is to be built and the use to which the customer will put the part may be clearly outlined. See Page 387. After this general consideration, specific load and service conditions are to be given attention, for these conditions indicate the type of joint to be used.

Types of Joint.—The type of joint to be used depends on load conditions to be met, i.e. whether it is steady, varying, fatigue or impact. (See Page 40 for discussion of joints and their load characteristics.)

As indicative of the method, assume that a butt joint is required. Several types of butt joints are available. The square grooved butt joint is the simplest, its preparation involving straight cuts to dimension, with opening between plates depending upon plate thickness. See Fig. 289.

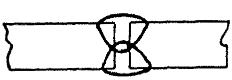


Fig. 289.

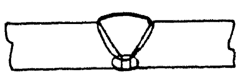


Fig. 290.

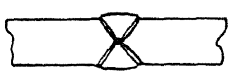


Fig. 291.

The single vee joint requires more preparation and more electrode than the square groove joint requires. See Fig. 290

With the double vee joint, shown in Fig. 291, cost of machining is higher than the single vee. However, it requires only half the amount of electrode for the same plate thickness.

Both the cost of machining and the cost of welding must be determined and the joint selected on the basis of lowest cost. In a given plant the cost per pound of deposited metal is known and the cost of machining per foot is known. A combination of these two, resulting in lowest cost, is selected. When basic cost figures are known this can be determined for the various types of joints and thickness of plates.

Forming, Cutting and Welding.—Welding and forming may be combined in fabrication of welded designs so as to reduce greatly the cost of a part. The container shown in Fig. 292 might be made in four parts as shown in Method No. 1 resulting in a weld on each corner. The scrap loss is low and the cuts are simple but the welding is considerable. If, however, the parts are cut as shown in Method No. 2, and bent along the edges, the welding footage is materially reduced. The cutting cost and the scrap loss are increased. The resultant product would be made of two pieces, bent along the edges.

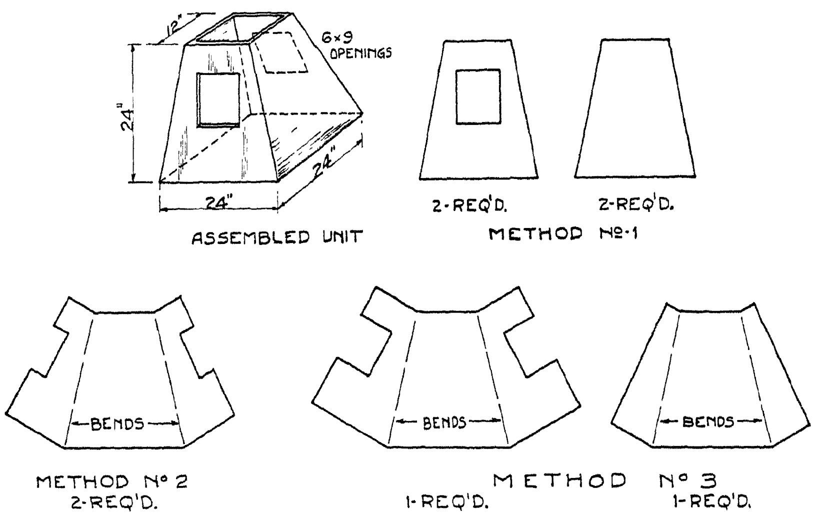


Fig. 292.

A modification of the design might be made as shown in Method No. 3. The factors, such as the type of equipment available in the plant will determine which combination of parts is most economical.

A direct comparison of costs is enlightening. Suppose the gross weight of the part is 30 lbs. and the cost of the welding is 18¢ per foot. With 2 ft. on a corner, or a total of 8 ft., the cost of welding is $1.44.

Compare this to the part in Method No. 2 where the total footage is $2\frac{1}{2}$, the cost is 45¢. As a matter of fact, the cost would really be

less than this because the joint in Method No. 2 which is a flat butt joint (square groove), might be welded in a fixture on a backing-up strip. It is, therefore, easier to make than the corner joint illustrated in Method No. 1.

Increase in scrap loss—say 25%—would make the gross weight 37½ lbs.

Resultant costs are:

Material (30 x 3¢)	$ .90
Welding	1.44
Total	$2.34
Material (37½ x 3¢)	$1.13
Welding	.45
Total	$1.58
Saving due to bending	$ .76

This saving does not include the cost of bending, yet this would be only a fraction of 76¢. Hence, in general, when proper equipment is available, it is more economical to form or bend than to weld.

Shapes are not only bent, formed and machined for welded designs, but they are also cut by gas. It is interesting to note that up to 5″ thick plate inclusive, the cost for *gas only* for a cut of 100 square inches is approximately 25¢ (at the average price of oxygen and acetylene). The speed of cutting increases rapidly as thickness of plate is reduced so that the labor charge varies. See Fig. 293.

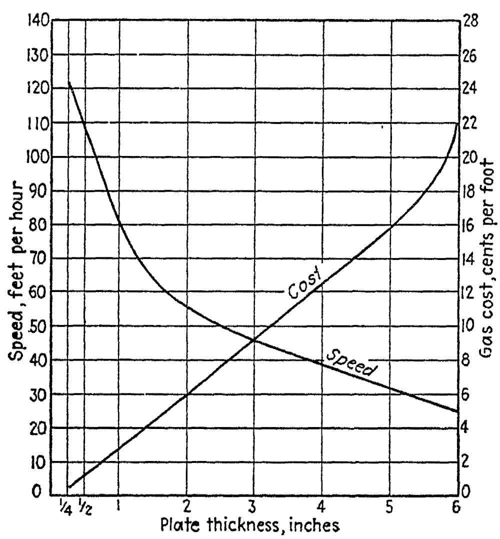
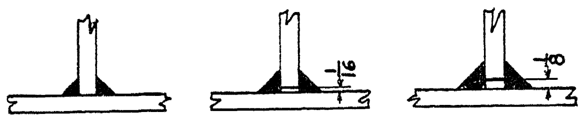


Fig. 293.

Note that as the thickness of the plate increases, production in square inches cut also goes up. For example, ¼-inch plate cut at a rate of 120 feet per hour is 360 sq. inches cut. Plate of ½-inch thickness, cut at a rate of 108 feet per hour is 648 sq. inches cut. Plate of one inch at 80 feet per hour is 1080 sq. inches cut. Economy through the use of large plate is obvious insofar as this factor of preparation is concerned.

The data as given are for no fatigue and no set-up allowances.

Fit-up.—Joints and their fit-up shoud be given most careful consideration, as fit-up affects not only the cost of the welded joint as such, but also the performance of the finished product. As an illustration of the effect upon cost in a very simple fit-up, notice the case shown in Fig. 294, where there is shown a T-weld with ¼″



Lbs./Ft. of Joint	.40	58	80
Cost/Ft.	$0 40	0 58	0.80
Increase in Cost		$0.18	0 40

Fig. 294.

plates. Assume that the cost per foot of joint is $0.40. (See page 215). If, however, there is a gap between the vertical plate and the horizontal plate of 1/16-inch, the cost is increased to $0.58 per foot. If this discrepancy is ⅛-inch, the cost is increased to $0.80 per foot, resulting in a difference of $0.18 to $0.40 for 1/16″ and ⅛″ respectively. Obviously money spent in obtaining good fit-up is readily saved in welding.

Sub Assemblies.—Detailed consideration of what at first might appear to be minor factors often results in startling cost reductions. A few simple examples illustrate this fact.

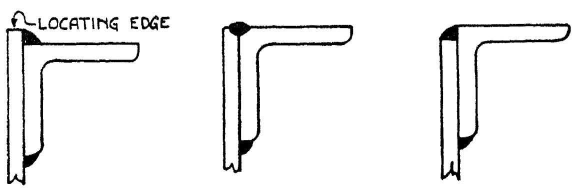


Fig. 295. Fig. 296. Fig. 297.

If an angle is to be joined to a plate primarily for stiffening and the edge of the plate serves as the locating surface, then the location of the angle is not of vital importance. (See Fig. 295.) However,

it may be easier to use the plan of Fig. 297, where the angle is the locating surface. Both of these are relatively easy to fabricate. However, the plan shown in Fig. 296 is more expensive, because both the angle and the plate are locating surfaces and it is necessary to scarf these or machine the weld. A little thought given to this item will save considerable money in the shop.

Fig. 298.

Next, take for example, the two joints shown in Fig. 298. In one case the plates require scarfing and in the other they do not. The comparison is obvious.

Another example is that of the joint of the two plates shown in Fig. 299. In one case, one plate is set back and the usual fillet

Fig. 299.

weld is made. In the other case, however, the one plate is not set in so far, and the base metal is melted and part of this base metal forms the bead. Reduction in cost results because the speed is higher and less electrode metal is required. This is comparable to a square-groove joint.

The relation of two parts to each other offers another study for cost reduction. Such a relationship is that of a head at the end of a casing as shown in Fig. 300. The head may be fitted inside the casing (left) which results in a rather difficult fit-up in order to obtain good contact between the head and the casing or wrapping plate. It requires that the parts be accurately made and that care be taken in the fit-up. (See Page 208.) In the other case (right), the head is placed on the end of the casing. This requires that the casing be straight—cut and bent—but it permits a slight adjustment of the dimensions of the casing and allows a quicker and easier fit-up.

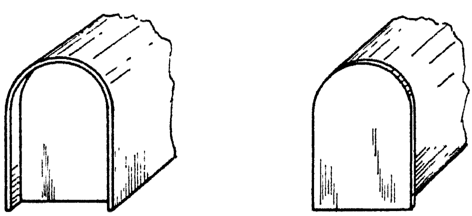


Fig. 300

Assembly.—Along the same general lines as above, the following illustrates the problem of final assembly.

Proper plate thickness to meet the requirements should be given

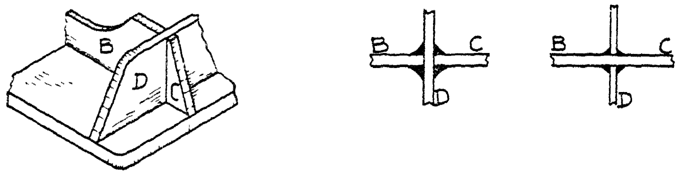


Fig. 301.

careful thought. Fig. 301 shows the corner of a machine. Looking at the joint, it might be possible to make the parts "B" and "C" of one piece of heavy plate, and the part "D" of lighter plate. Just a brief glance at the cross-section of these joints indicates how great the cost reduction may be.

It is true that welding itself is inherently a low-cost method of joining parts of metal, nevertheless indifference and thoughtlessness in designing may greatly decrease or nullify possible cost reduction. These various factors, kept in mind and given thought in the drawing room should produce substantial economies.

STUDY OF WELDING COSTS

Welding costs comprise the cost of *labor, electrode* and *power.*

Labor.—The cost due to labor depends on how many pounds of effective metal are deposited per hour—or in other words, how many

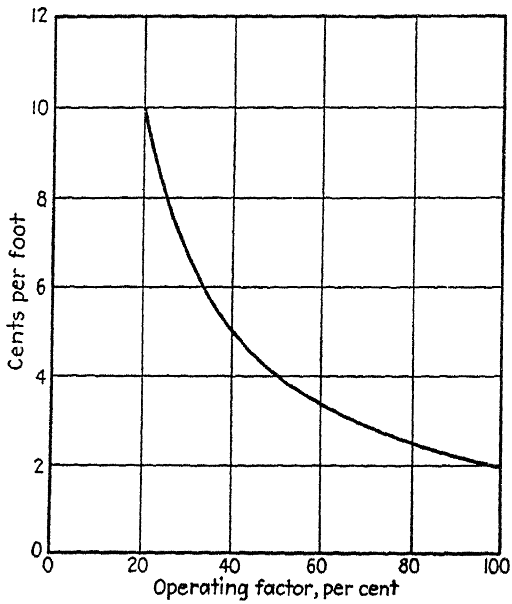


Fig. 302.

minutes per hour the arc is in operation. This time expressed in per cent is known as the *operating factor*. Obviously, this operating factor is in turn affected by positioning devices, jigs, fixtures, and other means for maintaining actual weld production.

As an example, assume a labor rate of $1.00 per hour and an *arc speed* of 50 ft. per hour. Arc speed is the actual rate of travel of the arc and may be expressed in inches per minute or feet per hour. For different operating factors the following costs result. This relation is shown in the curve of Fig. 302.

Operating Factor %	Production per Hour (Ft. per Hr.)	Cost per Foot
20	10	$0.10
40	20	0.05
60	30	0.0333
80	40	0.025
100	50	0.02

Inspection of the curve in Fig. 302 reveals that the greatest cost reduction can be made by maintaining maximum operating factor.

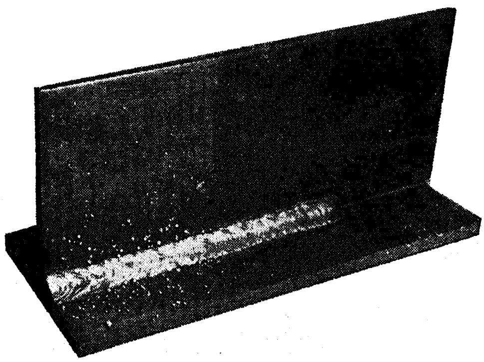


Fig. 303. Considerable cost reduction is possible in the production of welded parts through the application of special solutions to eliminate adherence of spatter. This solution is applied with an ordinary paint brush to the welded part. It cuts weld cleaning time 20% to 60%. The above fillet weld specimen, half of which was treated with this solution, illustrates how it reduces the adherence of spatter for less cleaning time.

Jigs and Fixtures.—One method of keeping the operating factor high is by the use of proper jigs and fixtures, and by proper set up. As an example of this, assume it takes a welder two minutes to weld a job and two minutes or slightly less to set it up. That is four minutes per part, or a total production rate of fifteen per hour. The use of jigs and fixtures is illustrated by providing a helper and another jig. The helper then can set up while the welder is welding and the production is increased to thirty units per hour, reducing costs materially. A production of fifteen parts per hour requires a jig, a welding machine and a welder, whereas thirty per hour require two jigs, a welding machine, one helper and a welder. Cost reduction is obvious because the second

fifteen parts are produced at the cost of one jig and one helper. See Fig. 304.

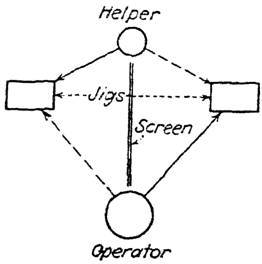


Fig. 304.

Another factor affecting the operating factor is the matter of working position. The work should be positioned so that it is easy and convenient for the welder to weld. For example, suppose that the

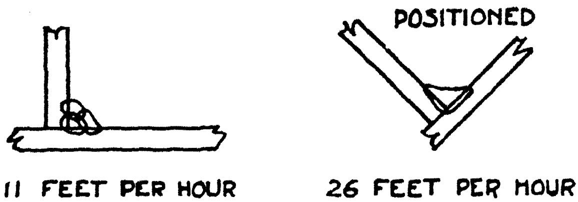


Fig. 305.

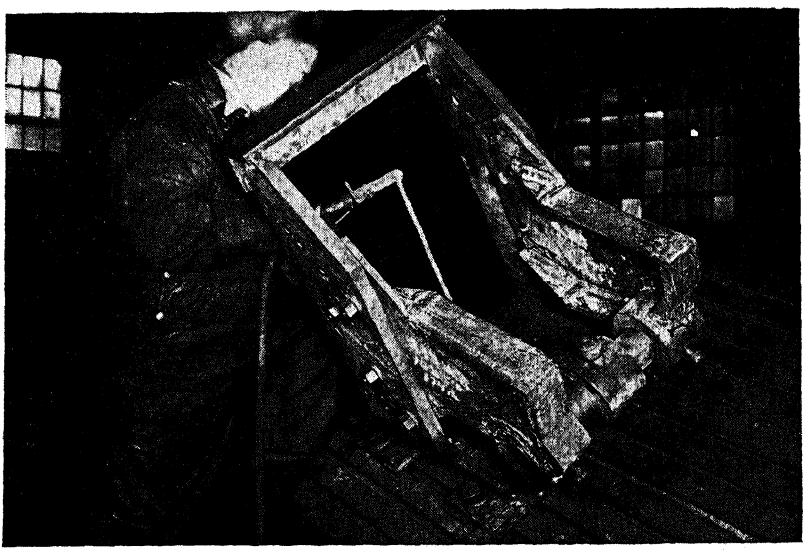


Fig. 306. This positioning jig and fixture permits the use of large electrodes for faster welding. Costs are further reduced in the manufacture of this machine part by using bending to fullest extent possible. (Heavy plate is bent hot.)

operator can always weld in the down-hand position. The speed will then be, say, 26 ft. per hour. If, however, it is necessary to weld it in the fillet position, the speed may be only 11 ft. per hour. (Actual arc speeds.) See Fig. 305.

Reduction of labor cost can be accomplished by obtaining a high operating factor and by the use of proper jigs and fixtures, obtaining proper positioning so as to make it possible to obtain high speeds. These factors are particularly controllable in welded fabrication.

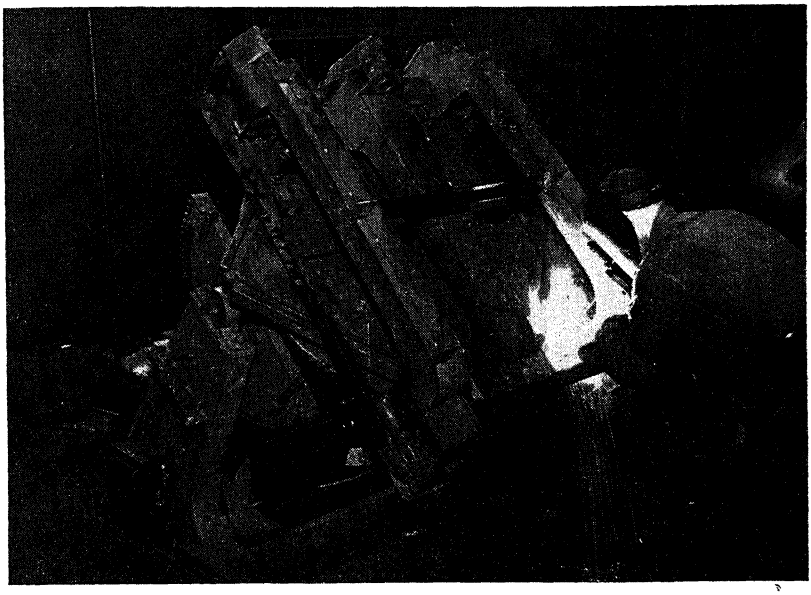


Fig. 307. Motor operated revolving tilting welding table. Permits down-hand welding of all joints in machine parts such as shown for substantial savings in welding time.

Fig. 308. These views of a 3-ton motor-operated welding positioner show how it brings the joints of a base into position for speedy, down-hand welding.

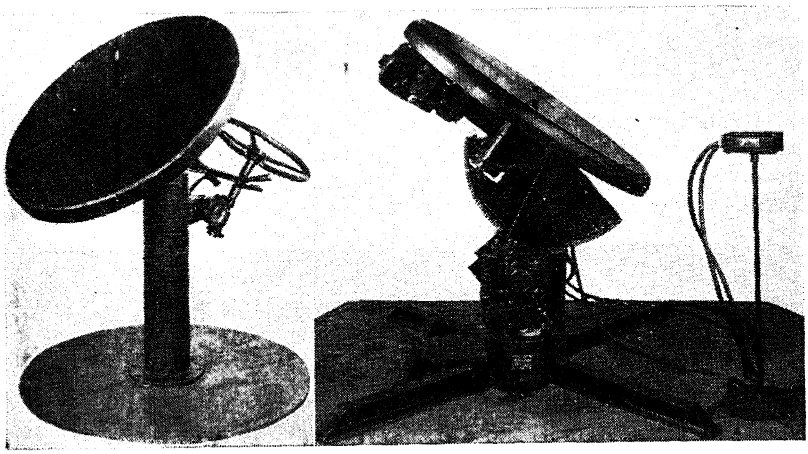


Fig. 309. Left: Hand-operated welding work positioner. Right: Motor-operated work positioner with push-button control and automatic limit switch cut-off. Note all-welded steel construction.

Electrodes.—Now, assume that the most favorable set-up has been devised—keep this factor fixed—and note the effect of changing arc time by means of electrodes.

Assume the following four arc speeds for different sizes or types of electrodes. The set-up time is the same in each case. To produce a unit of, say, 100 ft. of welding:

Arc speed per hr.	20	25	30	40
Arc time, hrs.	5	4	3.3	2.5
Set-up time, hrs.	2	2	2	2
Total time, hrs.	7	6	5.3	4.5
Cost (@ $2.00 per hr.)	14.00	12.00	10.60	9.00
Cost reductions	....	2.00	3.40	5.00
Production increases, % (Based on 7 hrs.)	....	17	32	55

Note that, in spite of the fact the set-up time is the same in the four cases, there is a marked increase in production with no increase in equipment or floor space. These factors are plotted in Fig. 310.

How can arc time be increased for minimum welding cost? There are two ways. One: Increase the *size* of electrodes. Two: Increase electrode deposition efficiency with the proper *type* of electrodes.

First, consider the effect of electrode size on the cost of deposited metal. Assume that deposition efficiency (ratio of amounts of deposited metal to total electrode consumed), the type of joint and all items except the electrode size are fixed. Labor is $1.00 per hour; power is $0.02 per k.w. hr.; operating factor (ratio of arc time to total time) is 50%; overhead is 100%; and deposition efficiency is 66⅔%. Vary the size of electrode as shown in the table below. The values for amperes, volts, consumption rates and welder efficiencies are obtained from Page 220.

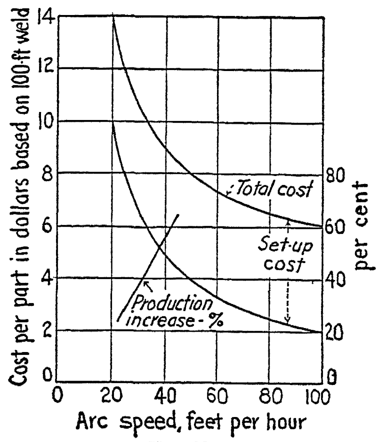


Fig. 310.

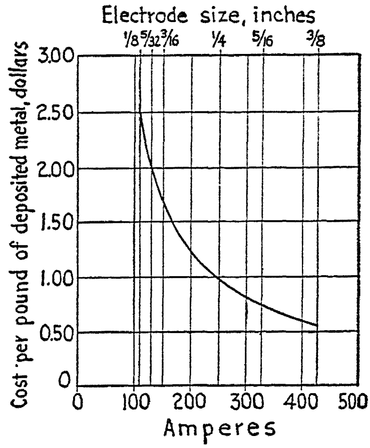


Fig. 311.

Interruptions per pound (for electrode changing) are based on the number of electrodes comprising a pound as purchased.

The costs per pound deposited for various size electrodes are tabulated below.

Effect of Changing Electrode Size

Electrode size	1/8	5/32	3/16	1/4	5/16	3/8
Amperes	110	130	150	250	325	425
Arc volts	24	25	26	30	34	38
K.W. at arc	2.64	3.25	3.9	7.5	11.1	16.1
Consumption rate, lbs. per hr.	2.6	3 3	3.95	7.5	10.7	16.2
Deposit, lbs. per hr. (50% operating factor)	0.87	1.1	1.32	2.5	3.57	5.4
Efficiency of set (%)	47	50	51	55	59	59
Kilowatt input	5 6	6.5	7 65	13.65	18.8	27.3
Interruptions per lb. consumed	18	12	8	5	3	2

Cost per Pound Deposited

Labor	$1.150	$0.909	$0.758	$0 400	$0.280	$0.185
Overhead	1.150	.909	.758	.400	.280	.185
Power	.064	.059	.058	.055	.053	.051
Electrode	.150	.135	.127	.127	.127	.127
Cost of interruption (including overhead)	.050	.033	.022	.014	008	.005
	$2.564	$2.045	$1 723	$0.996	$0 748	$0.553

Notes: K.W. at arc $= \frac{\text{Volts x Amps}}{1000}$

Consumption rate obtained by test or from procedure data.

Deposition per hour = Consumption rate x Deposition Efficiency x Operating Factor.

Efficiency obtained by test. (Also see Pg. 220.)

Interruptions = number electrodes per pound. Based on 2″ stub ends. See Page 216 for a discussion of the effect of stub ends on costs.

EFFECT OF STUB END LENGTH ON COSTS

The control of stub end losses, which are part of the cost of electrode, is an effective means of cost reduction, easily accomplished.

Its effectiveness is clearly indicated by a specific example. Compare the following tabulation to the costs given in the general table, which are for standard stub end losses (2-inch stub ends).

Cost (in cents) Per Pound Deposited for
Different Stub End Losses.

	¼" x 14" Electrode			
Stub Ends	2"	4"	6"	8"
Labor	.400	.407	.417	.440
Overhead	.400	.407	.417	.440
Power	.055	.055	.055	.055
Electrode (Includes Interruptions)	.141	.161	.200	.271
Total	$.996	1.030	1.089	1.205

For a ¼" x 18" electrode the cost difference is considerable.

Cost (in cents) per Pound Deposited

	¼" x 18" Electrode			
Stub Ends	2"	4"	6"	8"
Labor	$ .387	.391	.401	.406
Overhead	.387	.391	.401	.406
Power	.055	.055	.055	.055
Electrode (Including Interruptions)	.129	.149	.175	.209
Total	.958	.986	1.032	1.076

As a summation and general statement, note that (1) labor cost per pound deposited increases with increased stub end losses due to greater number of interruptions and lower operating factor, and (2) pounds of electrode per pound of deposit increases due to the stub end waste. On the average, labor costs increase 3% — for each 2" above the standard 2" stub end loss. For 14" electrode the average requirements are:

for 2" stub end loss 1.6 lbs. electrode per lb. deposited.
4" " " " 1.9 " " " " "
6" " " " 2.4 " " " " "
8" " " " 3.2 " " " " "

for 18" electrode
2" stub end loss 1.55 lbs. electrode per lb. deposited.
4" " " " 1.8 " " " " "
6" " " " 2.09 " " " " "
8" " " " 2.5 " " " " "

The cost control indicated by these figures is obvious.

As an example of savings made by increasing electrode size, note that by using ¼ in. size electrode instead of a 3⁄16 in. size, cost per pound deposited is reduced 42%. Plotting of the savings in the above table gives a curve as shown in Fig. 311.

Cost reduction is not the only benefit obtainable by using the largest size electrode practical. An improvement in quality of welding is often assured—especially where multiple passes are used. Distortion of the joint is less with the fewer number of passes required with larger electrodes. (See Page 97.)

Performance—This electrode factor concerns the melting rate, deposition efficiency and slag loss of various designs of electrodes without regard to electrode size. Since this factor affects the arc speed, it naturally affects the cost per foot of weld or per pound of deposited metal.

In an actual test, two ¼-in. electrodes of the same general characteristics were compared for performance economy with the following results:

	Electrode "A"	Electrode "B"
Size, in.	¼	¼
Amperes	340	340
Volts	34	34
Arc Kw	11.56	11.56
Efficiency Generator, per cent	59.5	59.5
Coating, per cent in 14 in.	22.2	20.1
Weight of Electrode, lb.	1.60	1.56
Weight, Stub Ends, lb.	0.231	0.386
Electrode used, lb.	1.369	1.174
Weight Plate—Deposit, lb.	15.860	15.790
Weight Plate, lb.	14.915	14.940
Weight Deposit, lb.	0.945	0.850
Time, Min.	7.867	5.916
Loss, per cent	30.94	27.55
Deposit lb. per hr.		

$$\left(\frac{0.945}{7.867} \times 60\right) = 7.22$$

$$\left(\frac{0.850}{5.916} \times 60\right) = \quad 8.62$$

The welding metal deposited was comparable in yield point, tensile strength and in elongation. The values were as follows:

Yield point	51,100	53,100
Tensile	64,800	65,100
Elongation 2″	19.9	23.1

The full effect of this difference in deposit rates on cost is evident by calculating it on the basis of say 10,000 lbs. of metal deposited. The assumptions and results are:

Labor	\$1.00 per hour
Power	0.02 per kwhr
Electrode	0.085 per lb.
Operation factor	50 per cent

Then time in hours to deposit:

$$10{,}000 \text{ lb.} = \frac{10{,}000}{7.22 \times 0.50} = 2770$$

$$\frac{10{,}000}{8.62 \times 0.50} = 2320$$

K.W.H. to deposit 1 lb. is:

$$\frac{11.56}{0.595 \times 7.22} = 2.69$$

$$\frac{11.56}{0.595 \times 8.62} = 2.25$$

Add ten per cent to results to take into account the idling losses.

Power for 10,000 lbs. = 29,600 KWH and 24,800 KWH

Electrode required: $\frac{10{,}000}{0.6906} = 14{,}480$ lbs.

and $\frac{10{,}000}{0.7245} = 13{,}800$ lbs.

Summation:	Electrode "A"	Electrode "B"
Hours to deposit 10,000	2,770	2,320
Kw-hr	29,600	24,800
Electrode, lb.	14,480	13,800

COSTS

Labor	\$2,770.00	\$2,320.00
Power	592.00	496.00
Material	1,231.00	1,175.00
	\$4,593.00	\$3,991.00

Saving with Electrode "A" \$602.00

Or, $\frac{\$602.00}{10{,}000} =$ 6c per lb. deposited (in the weld)

This saving is on the basis of per lb. of weld metal in the bead or deposit.

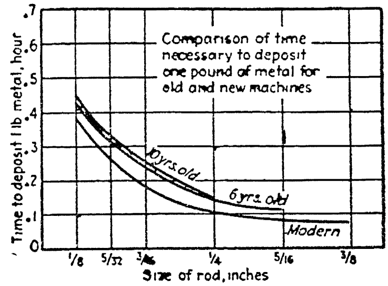
Six cents per lb. deposited is about 4¼c per lb. purchased, which is a very considerable item—50 per cent of the purchase price of electrode.

Power. — The costs due to power depend on the generator—its efficiency and size, and to some extent on the operating factor.

The Generator—Modern vs. Obsolete Designs—The deposition of metal involves the use of electric power, supplied by a welding gener-

ator which is usually driven by an electric motor. For purposes of this discussion, the motor driven type will be used.

In selecting a welding generator, the most modern design available should be secured in order to minimize costs. Reference to Fig. 312, which is based on test results, will illustrate this point. This is further exemplified by the following detailed test results:



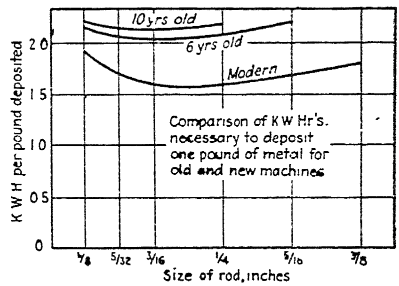


Fig. 312.

Length weld 896 inches	40 Volt Gen. (New)	25 Volt Gen. (Old)
Actual welding time — Min.	126.3	177.6
K.W.H. input per weld	22 3	24 8
Inches of weld per electrode	7.7	6 6

The cost reduction by the use of the modern 40 volt generator is obvious.

Note the reduction in time of 177 to 126 minutes, and an improvement in deposition from 6.6 inches of joint per electrode to 7.7 inches.

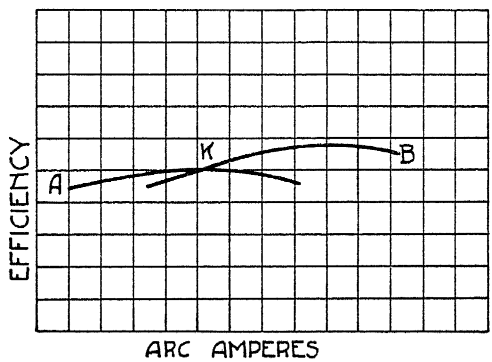


Fig. 313.

Generator Size—It is evident that generators of different sizes have different efficiency curves and that these curves may cross. This is illustrated in Fig. 313. If the larger percentage of the shop work is

applications with amperage requirements to the right of K, then the larger size machine (B) should be used because it is the most efficient.

It is well to remember that large electrodes reduce costs, as previously shown, and require higher currents which result in higher generator efficiencies.

Calculation of Efficiency—This is the governing item in the matter of power cost of depositing the metal. It is the efficiency of the welding generator at the various values of arc voltage and arc amperes. Usually efficiencies are given at different loads in amperes at 40 volts for 200 ampere generators and larger, and at 30 volts for smaller generators. See the following table.

EFFICIENCY OF GENERATOR—PER CENT

Operating Amperage	RATING OF GENERATOR					
	100 Amps.	150 Amps.	200 Amps.	300 Amps.	400 Amps.	600 Amps.
50	50	51	55			
100	52	58	60	58		
150		57	60	61	61	60
200		52	59	62	62	62
300			53	61	64	65
400				56	63	66
600					58	65
800						60

The efficiencies at arc voltage may be calculated approximately as follows:

Arc Amperes	200	300	400
KW Output at 40 V (arc)	8	12	16
Eff. 40 V % (See Table)	62	64	63
KW Input 40 V $\frac{\text{(Output)}}{\text{(Eff.)}}$	12.9	18.8	25.4
Arc Volts (Procedure)	28	32	37
Losses (Input — Output)	4.9	6.8	9.4
Output at Arc Volts	5.6	9.6	14.8
Input at Arc Volts	10.5	16.4	24.2

It is assumed that losses at the arc volts are equivalent to the losses at 40 volts. This is conservative. As the K.W. power input at the arc voltage is the desired quantity there is no need to calculate efficiency in per cent.

As an example of calculation of power costs, refer to the above table and calculate as follows:

Amperes	200	300	400
K.W. Input (arc volts)	10.5	16.4	24.2
Lbs. Deposited (electrode)	3.8	6.4	9.8
Lbs. Purchased	5.7	9.6	14.7
K.W.H. per Lb. Purchased	1.83	1.71	1.65
Cost of Power @ 2¢/K.W.H. (cents)	21	32.8	48.4
Cost of Electrode (@ 8½¢/lb.)	48.5	81.5	124.8

It is obvious that a welding generator, while welding, consumes power and produces welds, but a welding generator idling consumes power and produces no welds. It is therefore essential that the operating factor be kept high to minimize power costs. (See Page 210.)

General Cost Curve—Figures for the cost of electrode, and power for arc amperes of 200, 300 and 400 have been given above. Corresponding costs for other arc amperes may be calculated readily. If electrode cost, power cost, and the sum of these two are plotted against arc amperes in the form of curves, the costs of electrode and power for any value of arc amperes are obtainable from the curve. See Fig. 314. If to the sum of electrode and power costs is added the labor item (the labor rate divided by the operating factor), the total may be called the "cost per hour." This total divided by actual arc speed gives the cost per foot of bead. For multiple beads the cost per foot of weld is obtained by adding cost per foot for each component bead.

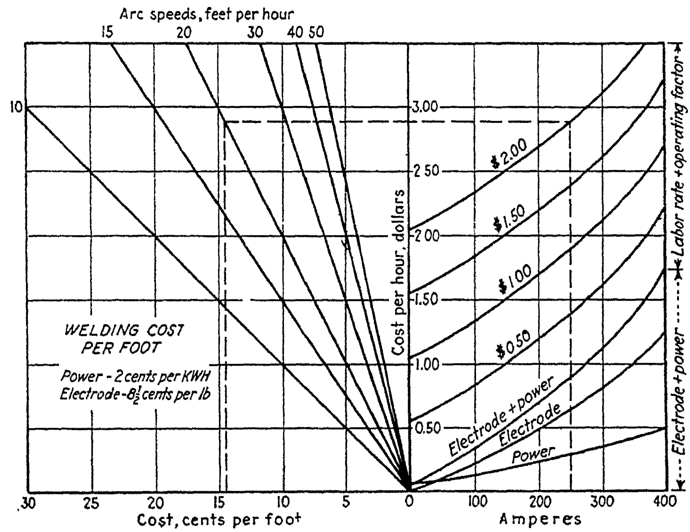


Fig. 314

Position, type of joint, deposition efficiency — all these factors govern speed. Speed used is *arc* speed. Labor item is the hourly labor rate divided by the operating factor. If this item is divided by arc speed

the result is labor cost per foot. Electrodes and power are consumed during operation. Instead of dividing each item, electrode, power and labor, by the speed, and then adding these three, their sum is divided by speed and the result is cost per foot.

For example, at 250 arc amperes with labor at $1.00 per hour and an operating factor of 50%, the labor item would be $1.00 divided by 50% or $2.00. For an arc speed of 20 ft. per hour the cost would be obtained by starting at 250 amperes, going to the labor item marked $2.00, horizontally to the arc speed curve "20 ft. per hour" and down to the cost per foot of 14.5¢. This may be further simplified in individual specific cases as for example, assume that the power costs 2¢ per K.W.H. and electrode costs 8½¢ per lb., labor is $1.00 per hour and the operating factor is 66⅔%. The labor item is then $1.50. The tabulation is:

Amperes	200	300	400
Electrode + Power (cents)	69.5	114.3	173.2
Labor Item	150	150	150
Total Cost (¢)	219.5	264.3	323.2

This tabulation may be plotted as indicated in Fig. 315.

The arc amperes are plotted and the cost of operation scale are plotted together in one scale. This cost of operation is divided by the speed giving the cost per foot.

Another arrangement of these basic facts is the tabulations for specific joints, such as given on Pages 223 to 237.

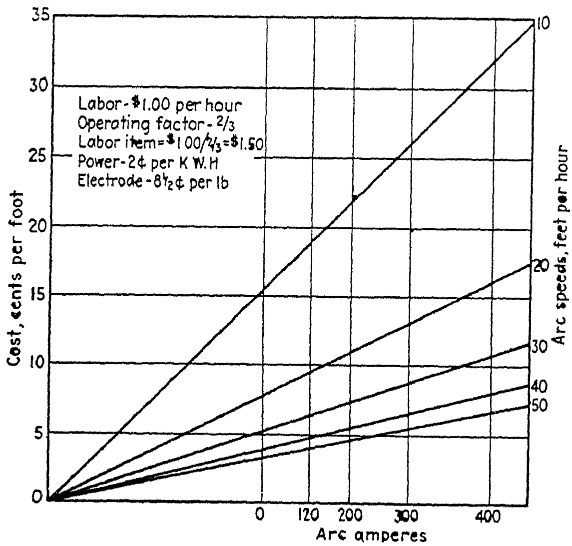


Fig. 315

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 156): Square Groove Butt Welds—
Flat Position — Two Passes — With "Type A" Electrodes
TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		35	30	25	22.5	20	17.5	15	12.5	10	7.5	5
TOTAL COST — Cents for Various Plates	3/16	4.68	5.15	5.82	6.26	6.82	7.54	8.49	9.82	11.82	15.14	———
	1/4	5.95	6.42	7.09	7.53	8.09	8.81	9.76	11.09	13.09	16.41	———
	3/8	———	8.64	9.31	9.75	10.31	11.03	11.98	13.31	15.31	18.63	25.31
	1/2	———	———	———	———	15.44	16.16	17.11	18.44	20.44	23.76	30.44

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 157):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1-2	1/4	190	30	53.5	94	47	.16
1/4	1-2	5/16	300	34	58	90	45	.27
3/8	1-2	5/16	425	38	59	75	37.5	.45
1/2	1-2	3/8	500	40	60	50	25	.92

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8 ½c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1-2	5.7	10.65	21.3	$\frac{.238}{.456}$	1.36	1.82
1/4	1-2	10.2	17.6	35.2	$\frac{.394}{.788}$	2.3	3.09
3/8	1-2	16.15	27.4	54.8	$\frac{.74}{1.48}$	3.83	5.31
1/2	1-2	20.0	33.3	66.6	$\frac{1.32}{2.64}$	7.8	10.44

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	35	30	25	22.5	20	17.5	15	12.5	10	7.5	5
Labor Cost/Ft. of Joint	2.86	3.33	4.0	4.44	5.0	5.72	6.67	8.0	10 0	13.32	20.0

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

Explanation

Example: Calculations for straight butt welds, flat position, two passes, with "Type A" electrodes: See Page 157.

Total Production Cost—This table gives costs in cents for various floor-to floor speeds and plate thicknesses.

> *Floor-to-floor speed* — This term designates the rate of production including actual arc time, plus handling time, plus time out for changing electrode, and so forth. In other words, it is the arc speed divided by the operating factor. This quantity varies for different shops. A wide range of speeds is given so as to fit the conditions of highly efficient shops as well as those with inefficient setups for welding.

Total production cost is derived by calculating and adding: (1) Power cost. (2) Electrode cost. (3) Labor cost per foot of joint. Following is the procedure.

(A) — DATA — The data for this particular type of joint are obtained from Page 157 and arranged in tabular form as shown with each column given a reference number. Col. 6 (per cent efficiency) is obtained from the table on Page 220.

Arc speed in feet of bead per hour (Col. 7) is not given in every case for the procedures and speeds of various joints. This has been derived for certain joints by interpolating from the arc speed in feet of joint per hour. It often varies for different passes even though the same size electrode is used depending upon whether or not weaving is employed. This arc speed for each bead affects the total power cost.

(B) — CALCULATION OF POWER AND ELECTRODE COSTS — These calculations are based on the data given in Table (A). Take for example calculation of costs for a ⅜-inch plate.

> *Arc Kilowatts* — This item as shown in Col. 10 is derived by multiplying the welding amperes (Col. 4) by the arc voltage (Col. 5) and dividing by 1000. In other words, 425 times 38 divided by 1000 equals 16.15.
>
> *Input Kilowatts* — The power input of the welding machine is equal to the power output (arc kilowatts) divided by the welder efficiency at arc voltage. In other words, 16.15 divided by .59 equals 27.4 as shown in Col. 11.

Power Cost Per Hour — This item as shown in Col. 12 is the power input multiplied by the prevailing rate for KWH. In all of these calculations the rate of 2¢ per KWH is assumed. For the example given, this cost would therefore be 27.4 times 2 equals 54.8¢ per hour.

Power Cost Per Foot — This item in Col. 13 is derived by dividing the power cost per hour by the arc speed per hour. Inasmuch as this factor varies for different beads in the weld, it is calculated on the basis of cost per bead then totalled to get the cost per foot of weld. In order to save space in the printing of these tables the data for a series of beads where the various quantities are the same are not repeated but are included in one line designated for the entire series of passes. The total power cost per foot of joint is separated from the power costs of an individual pass of a series of passes by a line as shown in this example. Deriving the power cost for this particular plate thickness we have: 54.8 divided by 75 equals .74¢ per foot of bead. Then the total power cost per foot of joint is .74 times 2 (passes) equals 1.48¢ per foot of joint.

Electrode Cost Per Foot — This item in Col. 14 is derived by multiplying the electrode pounds per foot by the prevailing cost of electrodes per pound. In these calculations it is assumed that the cost of electrodes is 8½¢, which is a conservative figure. However, this price varies with the shipping zone and the quantity purchased. For the example being discussed, the electrode cost is .45 times 8½ equals 3.83¢ per foot of joint.

Power Plus Electrode Cost — The sum of the power and electrode cost for this particular joint would be 1.48 plus 3.83 equals 5.31¢ per foot of joint.

(C) — CALCULATION OF LABOR COST — In these calculations the cost of labor is assumed to be $1.00 per hour (excluding overhead). Labor cost per foot of joint is derived by dividing the labor rate by the production (floor-to-floor) speed. In other words assuming a floor-to-floor speed of 20 feet per hour, the labor cost per foot would be $1.00 divided by 20 equals 5¢ per foot of joint.

To change the information given in these tables when labor rate is other than $1.00 per hour, it is simply necessary to multiply the labor cost per foot given in the table by the prevailing rate in cents and divide this by 100. For example, if the rate is $1.25 per hour, the labor cost for ⅜-inch plate at a floor-to-floor speed of 20 feet per hour would be: 5.0 times 125 divided by 100, equals 5.0 times 1.25 equals 6.25¢ per foot of joint.

Total Production Cost — As stated above, the total production cost is power cost plus electrode cost plus labor cost. In other words, for the ⅜-inch plate discussed, at a floor-to-floor speed of 20 feet per hour, the total cost is 5.31 (Col. 15) plus 5.0 equals 10.31¢ per foot of joint as shown in the table at the top of the page.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 155): Butt Joints—Flat Position—Single V-Groove—No Backing—With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		30	25	20	18	16	14	12	10	8	6	4	2
TOTAL COST — Cents for Various Plates	1/4	—	—	—	—	—	11.3	12.4	14.1	16.6	20.7	29.1	54.1
	3/8	—	—	—	—	—	—	—	16.57	19.07	23.17	31.57	56.57
	1/2	—	—	—	—	—	—	—	—	23.99	28.09	36.49	61.49

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 155):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of Joint/hr.	9 Electrode Consumed Lbs./Ft. joint
1/4	1 2	5/32 3/16	130 175	25 28	50 52.5	45 25	17.5	11 25 .36
3/8	1 2	5/32 1/4	130 225	25 30	50 54 5	32.5 20	13	.15 .43 58
1/2	1 2 3 4	5/32 1/4 1/4 5/16	130 225 275 325	25 30 30 34	50 54 5 55 57	30 36 40 38	9	.16 .24 26 .35 1.01

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
1/4	1 2	3.25 4.9	6 5 9 35	13 18 7	.29 75 1.04	3.86	4.1
3/8	1 2	3 25 6.75	6.5 12.4	13 24 8	.40 1.24 1 64	4 93	6.57
1/2	1 2 3 4	3 25 6 75 8.25 11.1	6.5 12.4 15 19.4	13 24.8 30 38.8	.43 .69 .75 1 02 2 89	8.6	11.49

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	30	25	20	18	16	14	12	10	8	6	4	2
Labor Cost/ Ft. of Joint	3 33	4 0	5 0	5 5	6 25	7 2	8.3	10.0	12.5	16.6	25.0	50.0

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 202): Butt Joints—Flat Position—"U" Groove—No Backing—With "Type C" Deep Groove Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		6	5	4	3	2	1	.5
TOTAL COST —Cents for Various Plates	¾	37.32	40.62	45.62	53.92	70.62	120.62	220.62
	1			56.57	64.87	81.57	131.57	231.57
	1½				78.95	95.65	145.65	245.65

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 202):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
¾	1	3/16	220	24	52	50		
	2	¼	340	29	57	45		
	3-4	¼	340	29	57	40		
	5	¼	300	29	57	40		
	6	¼	340	29	57	55	7 5	1 9
1	1	3/16	220	24	52	45		
	2-6	¼	340	29	57	35		
	7	¼	300	29	57	35	4 75	2 9
	8	¼	340	29	57	50		
1½	1	3/16	220	24	52	45		
	2-10	¼	340	29	57	38		
	11	¼	300	29	57	38	3 25	4 2
	12	¼	340	29	57	50		

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
¾	1	5 28	10.2	20 4	.41		
	2	9.86	17 3	34 6	.77		
	3-4	9.86	17 3	34 6	.87		
	5	5.7	15 2	34.6	.87		
	6	9.86	17 3	34 6	.63	16.2	20 62
					4.42		
1	1	5.28	10.2	20.4	.46		
	2-6	9.86	17 3	34.6	.99		
	7	8 7	15 2	30.4	.87		
	8	9.86	17.3	34 6	.69	24 6	31 57
					6.97		
1½	1	5.28	10 2	20.4	.46		
	2-10	9.86	17.3	34.6	.91		
	11	8.7	15 2	30.4	.80		
	12	9.86	17.3	34.6	.70	35.6	45.65
					10 05		

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed —Ft./Hr.	6	5	4	3	2	1	.5
LABOR COST/FT. OF JOINT	16.7	20	25	33.3	50	100	200

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 168): Butt Welds—No Backing—Horizontal Position—Plate Scarfed 20° Lower Angle, 45° Upper Angle—With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed—Ft./Hr.		20	18	16	14	12	10	8	6	4	3	2
TOTAL COST —Cents for Various Plates	3/16	6.9	7.4	8.15	9.1	10.2	11.9	14.4	18.5	26.9	—	—
	1/4	—	—	—	9.9	11.0	12.7	15.2	19.3	27.7	36.0	—
	3/8	—	—	—	—	—	—	16.95	21.05	29.45	37.78	54.45
	1/2	—	—	—	—	—	—	—	—	35.26	43.6	60.26

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 169):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1-2	5/32	130	25	50	48	24	.16
1/4	1-2	5/32	130	25	50	35	17.5	.23
3/8	1-3	5/32	130	25	50	31.5	10.5	.38
1/2	1-8	5/32	130	25	50	35.2	4.4	.86

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1-2	3.25	6.50	13	.27 .54	1.36	1 90
1/4	1-2	3.25	6.50	13	.37 .74	1.95	2.69
3/8	1-3	3.25	6.50	13	.41 1.23	3.22	4.45
1/2	1-8	3.25	6.50	13	.37 2.96	7.30	10.26

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	20	18	16	14	12	10	8	6	4	3	2
Labor Cost/Ft. of Joint	5.0	5.5	6.25	7.2	8.3	10.0	12.5	16.6	25.0	33.3	50

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 166): Butt Joints — Vertical Position — Welding Upward — With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr		20	18	16	14	12	10	8	6	4	3	2	1
TOTAL COST —Cents for Various Plates	3/16	—	—	8.07	9.02	10.12	11.82	14.32	18.42	26.82	35.12	—	—
	1/4	—	—	—	—	11.08	12.78	15.28	19.38	27.78	36.08	52.78	—
	3/8	—	—	—	—	—	—	17.68	21.78	30.18	38.48	55.18	—
	1/2	—	—	—	—	—	—	—	—	32.74	41.04	57.74	107.74

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds — Page 166):

Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1	1/8	110	25	50	20	20	.15
1/4	1	1/8	110	25	50	15	15	.24
3/8	1 2	5/32 5/32	130 130	25 25	50	20 19	9.75	.44
1/2	1 2	5/32 5/32	130 130	25 25	50	11 10	5.25	72

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1	2.75	5.5	11	.55	1.27	1.82
1/4	1	2 75	5.5	11	.74	2 04	2 78
3/8	1 2	3 25 3 25	6 50 6 50	13 13	65 68 1 33	3 75	5 18
1/2	1 2	3 25 3 25	6.50 6 50	13 13	1.19 1 3 2 49	6.12	7.74

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	20	18	16	14	12	10	8	6	4	3	2
Labor Cost/ Ft. of Joint	5 0	5.5	6.25	7 2	8 3	10.	12 5	16 6	25.	33.3	50

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 165): Butt Joints—Vertical Position—Welding Downward—With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		20	18	16	14	12	10	8	6	4	3	2
TOTAL Cost —Cents for Various Plates	3/16	7.03	7.53	8.28	9.23	10.3	12.03	14.53	18.63	27.03		
	1/4				10.48	11.58	13.28	15.78	19.88	28.28	36.58	
	3/8							17.69	21.79	30.19	38.49	55.19
	1/2								24.87	33.27	41.57	58.27

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 165):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1 2	1/8 3/16	110 150	25 25	50 50	55 45	25	18
1/4	1 2	1/8 3/16	110 150	25 25	50 50	40 30	17 5	29
3/8	1 2 3	3/16 3/16 3/16	150 150 150	25 25 25	50 50 50	28 33 38	11	44
1/2	1 2 3-5	3/16 3/16 3/16	150 150 150	25 25 25	50 50 50	28 33 38	7	.72

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1 2	2 75 3 75	5.5 7 5	11 0 15 0	.2 33 .53	1 5	2 03
1/4	1 2	2 75 3 75	5.5 7 5	11.0 15 0	28 50 78	2.5	3 28
3/8	1 2 3	3 75 3 75 3 75	7 5 7.5 7.5	15 0 15 0 15 0	54 .46 .39 1 39	3 8	5.19
1/2	1 2 3-5	3.75 3 75 3.75	7.5 7.5 7.5	15 0 15 0 15 0	.54 .46 .39 2.17	6.1	8.27

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	20	18	16	14	12	10	8	6	4	3	2
Labor Cost/ Ft. of Joint	5 0	5 5	6 25	7.2	8.3	10	12 5	16 6	25.	33.3	50

Note. See explanation on Pages 224-225.

CALCULATION OF WELDING PRODUCTION COSTS

TYPE OF JOINT (See Page 167): Butt Welds—Overhead Position—With "Type A" Electrodes

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		11	10	9	8	7	6	5	4	3	2	1.0	.5
TOTAL COST —Cents for Various Plates	3/16	12.95	13.85	14.95	16.35	18.05	20.55	23.85	28.85	36.85	53.85	103.85	203.85
	1/4	—	—	—	—	19.55	22.05	25.35	30.35	38.35	53.35	105.35	205.35
	3/8	—	—	—	—	—	—	29.2	34.21	42.21	59.21	109.21	209.21
	1/2	—	—	—	—	—	—	—	—	46.29	63.29	113.29	213.29

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 167):

Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1 2	1/8 3/16	110 150	25 25	50 50	30 26	14	.33
1/4	1 2 3	1/8 3/16 3/16	110 150 150	25 25 25	50 50 50	30 26 25	9	.45
3/8	1 2 3 4	1/8 5/32 3/16 3/16	110 130 150 150	25 25 25 25	50 50 50 50	28 25 23 20	6	.70
1/2	1 2-3 4-7	1/8 5/32 3/16	110 130 150	25 25 25	50 50 50	28 28 28	4	1.15

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1 2	2.75 3.75	5.5 7.5	11 15	.37 .58 .95	2.9	3.85
1/4	1 2 3	2.75 3.75 3.75	5.5 7.5 7 5	11 15 15	.37 .58 .60 1.55	3.8	5.35
3/8	1 2 3 4	2.75 3.25 3.75 3.75	5.5 6.5 7.5 7.5	11 13 15 15	.39 .52 .65 .75 2.31	6.9	9.21
1/2	1 2-3 4-7	2.75 3.25 3.75	5.5 6.5 7.5	11 13 15	.39 .47 .54 3.49	9.8	13 29

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	11	10	9	8	7	6	5	4	3	2	1.0	.5
LABOR COST/ FT. OF JOINT	9.1	10	11.1	12.5	14.2	16.7	20	25	33	50	100	200

Note: See explanation on Pages 224-225.

CALCULATION OF WELDING PRODUCTION COSTS

TYPE OF JOINT (See Page 171): Fillet Welds — Flat Position — With "Type A" Electrodes

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed—Ft./Hr.		35	30	25	20	15	10	8	6	4	2
TOTAL COST —Cents for Various Plates	3/16	4.65	5.12	5.79	6.79	8.45	11.79	14.29	18.39	26.79	51.79
	1/4	—	—	6.31	7.31	8.97	12.31	14.81	18.91	27.31	52.31
	3/8	—	—	—	—	10.86	14.2	16.7	20.8	29.2	54.2
	1/2	—	—	—	—	—	—	20.58	24.68	33.08	58.08

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 171):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1	1/4	190	30	53.5	45	45	.155
1/4	1	1/4	190	30	53.5	35	35	.20
3/8	1	1/4	190	30	53 5	20	20	.37
1/2	1-3	1/4	190	30	53.5	30	10	.7C

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1	5.7	10.65	21.3	.473	1.32	1.79
1/4	1	5.7	10.65	21.3	.61	1.7	2.31
3/8	1	5.7	10.65	21.3	1.06	3.14	4.20
1/2	1-3	5.7	10.65	21.3	.71 2.13	5.95	8.08

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	35	30	25	20	15	10	8	6	4	2
LABOR COST/FT. OF JOINT	2.86	3 33	4.0	5.0	6.66	10.0	12.5	16.6	25.0	50.0

Note: See explanation on Pages 224-225.

CALCULATION OF WELDING PRODUCTION COSTS

TYPE OF JOINT (See Fig. 281): Fillet Welds—Flat, Tilted Position—With "Type C" Fillet Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		40	30	25	20	15	12.5	10	8	7	6	5	4	3	2
TOTAL COST —Cents for Various Plates	3/16	4.26	5.09	5.76	6.76	8.43	9.76	11.76	14.26	—	—	—	—	—	—
	1/4	5.23	6.06	6.73	7.73	9.40	10.73	12.73	15.23	—	—	—	—	—	—
	3/8	6.82	7.65	8.32	9.32	10.99	12.32	14.32	16.82	18.62	21.02	—	—	—	—
	1/2	—	—	10.08	11.08	12.75	14.08	16.08	18.58	20.38	22.78	26.08	—	—	—
	3/4	—	—	—	—	—	22.61	24.61	27.11	28.91	31.31	34.61	39.61	47.91	—
	1	—	—	—	—	—	—	—	32.81	39.11	41.51	44.81	49.81	58.11	74.81

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 200):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1	3/16	250	21	50	53	53	.16
1/4	1	1/4	350	24	52	53	53	.25
3/8	1	5/16	500	26	54	48	48	.39
1/2	1	5/16	500	26	54	34	34	.55
3/4	1 2	5/16 3/8	500 600	26 28	54 56	34 30	16	1.32
1	1 2 3	5/16 3/8 3/8	500 600 600	26 28 28	54 56 56	34 30 26	10	2 25

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1	5 25	10 5	21	.40	1.36	1.76
1/4	1	8.4	16 2	32 4	61	2 12	2.73
3/8	1	13.0	24	48	1 00	3 32	4.32
1/2	1	13.0	24	48	1 41	4.67	6 08
3/4	1 2	13.0 16 8	24 30	48 60	1.41 2 00 3.41	11 2	14.61
1	1 2 3	13 16 8 16.8	24 30 30	48 60 60	1.41 2.00 2.30 5 71	19.1	24 81

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	40	30	25	20	15	12.5	10	8	7	6	5	4	3	2
LABOR COST/ FT. OF JOINT	2.5	3.33	4.0	5.0	6.67	8	10	12.5	14.3	16.7	20	25	33.3	50

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 173): Lap Joints—Flat Position—With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		80	70	60	50	40	30	25	20	15	10	7.5
TOTAL COST —Cents for Various Plates	1/8	2.35	2.53	2.77	3.	3.6	4.43	5.1	6.1	7.77	....	....
	3/16	....	2.80	3.04	3.37	3.87	4.70	5.37	6.37	8.04	....	....
	1/4	....	....	....	3.56	4.06	4.89	5.56	6.56	8.23	11.56	14.86
	5/16	....	....	....	....	4.67	5.50	6.17	7.17	8.84	12.17	15.47
	3/8	....	....	....	....	....	6.01	6.68	7.68	9.35	12.68	15.98

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 173):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
1/8	1	1/4	250	30	55	100	100	.097
3/16	1	1/4	275	30	55	90	90	.120
1/4	1	1/4	250	30	55	70	70	.138
5/16	1	1/4	250	30	55	50	50	.19
3/8	1	1/4	250	30	55	40	40	.237

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col 9 × 8 5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
1/8	1	7.5	13.6	27.2	.272	.83	1.102
3/16	1	8.25	15	30	.333	1.04	1.373
1/4	1	7.5	13.7	27.4	.390	1.17	1.56
5/16	1	7.5	13.7	27.4	.548	1.62	2.168
3/8	1	7.5	13.7	27 4	.685	2.00	2.685

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	80	70	60	50	40	30	25	20	15	10	7.5
Labor Cost/Ft. of Joint	1.25	1.43	1 67	2 0	2.5	3.33	4 0	5.0	6.67	10	13.3

Note: See explanation on Pages 224-225

CALCULATION OF WELDING PRODUCTION COSTS

TYPE OF JOINT (See Page 175): Lap Joints—Vertical Position—Welding Upward—With Type "A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		15	12	10	8	6	5	4	3	2	1	.5
TOTAL COST —Cents For Various Plates	3/16	8.62	10.30	11.96	14.46	18.66	21.96	26.96	35.26			
	1/4	9.33	11.01	12.67	15.17	19.37	22.67	27.67	35.97			
	3/8					21.67	24.97	29.97	38.27	54.97		
	1/2						28.7	33.7	42	58.7	108.7	
	1/2						28.4	33.4	41.7	58.4	108.4	
	3/4									66.9	116.9	216.9
	1										130.9	230.9

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 176):

Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1	1/8	110	25	50	18	18	.16
1/4	1	5/32	130	25	50	18	18	.23
3/8	1	5/32	130	25	50	9 5	9 5	.42
1/2	1-2	5/32	130	25	50	10	5	72
1/2	1-2	3/16V	150	25	50	13	6.5	.72
3/4	1-3	3/16V	150	25	50	9.75	3 25	1 45
1	1-4	3/16V	150	25	50	6 8	1.7	2 60

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 × Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1	2 75	5 5	11	.61	1.35	1.96
1/4	1	3.25	6.5	13	.72	1.95	2.67
3/8	1	3 25	6.5	13	1.37	3.6	4 97
1/2	1-2	3.25	6.5	13	1.3 2 6	6 1	8.7
1/2	1-2	3.75	7.5	15	1.15 2.3	6.1	8 4
3/4	1-3	3.75	7.5	15	1.53 4.6	12.3	16 9
1	1-4	3.75	7.5	15	2 22 8 9	22.0	30 9

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	15	12	10	8	6	5	4	3	2	1	5
LABOR COST/ FT. OF JOINT	6.66	8 34	10	12.5	16.7	20	25	33 3	50	100	200

Note: See explanation on Pages 224-2^^

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 175): Lap Joints — Vertical Position — Welding Downward — With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		30	25	20	15	10	8	6	4	3	2	1	.5
TOTAL COST —Cents for Various Plates	3/16	4.86	5.53	6.53	8.19	11.53	14.03	18.23	26.53	—	—	—	—
	1/4	—	—	—	9.55	12.89	15.39	19.59	27.89	36.19	52.89	—	—
	3/8	—	—	—	—	14.65	17.15	21.36	29.65	37.95	54.95	—	—
	1/2	—	—	—	—	—	—	—	33.4	41.7	58.4	108.4	—
	3/4	—	—	—	—	—	—	—	—	50.7	67.4	117.4	217.4
	1	—	—	—	—	—	—	—	—	—	—	132.22	232.22

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 175):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1	3/16	150	25	50	35	35	.12
1/4	1-2	3/16	150	25	50	38	19	25
3/8	1-3	3/16	150	25	50	36	12	.40
1/2	1-5	3/16	150	25	50	32.5	6.5	.72
3/4	1-9	3/16	150	25	50	29.25	3 25	1.5
1	1-14	3/16	150	25	50	23.8	1 7	2.75

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1	3.75	7.5	15	.43	1.1	1.53
1/4	1-2	3.75	7 5	15	.395 .79	2.1	2.89
3/8	1-3	3.75	7 5	15	416 1 25	3.4	4.65
1/2	1-5	3 75	7 5	15	.46 2 3	6.1	8.4
3/4	1-9	3.75	7 5	15	51 4 6	12.8	17.4
1	1-14	3.75	7.5	15	.63 8 82	23.4	32.22

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	30	25	20	15	10	8	6	4	3	2	1	.5
Labor Cost/ Ft. of Joint	3.33	4.0	5.0	6 66	10	12.5	16.7	25	33.3	50	100	200

Note: See explanation on Pages 224-225.

Calculation of Welding Production Costs

TYPE OF JOINT (See Page 176): Lap Joints—Overhead Position—With "Type A" Electrode

TOTAL PRODUCTION COST PER FOOT OF JOINT (Cents):

Floor-to-floor Speed — Ft./Hr.		30	25	20	15	12	10	8	6	4	3	2
TOTAL COST —Cents for Various Plates	3/16	4.78	5.45	6.45	8.11	9.78	11.45	13.95	18.15	26.45	—	—
	1/4	—	—	—	—	11.43	13.1	15.6	19.8	28.1	36.4	53.1
	3/8	—	—	—	—	—	—	18.7	22.9	31.2	39.5	56.2
	1/2	—	—	—	—	—	—	—	—	33.7	42.0	58.7

DERIVED AS FOLLOWS:

(A) DATA (From tables of procedures and speeds—Page 176):

1 Plate Thickness	2 Pass Number	3 Size Electrode	4 Welding Amperes	5 Arc Voltage	6 Per Cent Efficiency At arc voltage	7 Arc Speed Ft. of bead/hr.	8 Arc Speed Ft. of joint/hr.	9 Electrode Consumed Lbs./Ft. joint
3/16	1	3/16	150	25	50	35	35	.12
1/4	1 2	3/16 1/8	150 110	25 25	50 50	30 30	15	26
3/8	1-3 4	3/16 1/8	150 110	25 25	50 50	20 18	9 5	.53
1/2	1-5	3/16	150	25	50	32.5	6 5	.75

(B) CALCULATION OF POWER AND ELECTRODE COSTS (Cents):

Plate	Pass	10 Arc Kilowatts (Col. 4 × Col. 5 ÷ 1000)	11 Input Kilowatts (Col. 10 ÷ Col. 6)	12 Power Cost/Hr. (Col. 11 × 2c)	13 Power Cost/Ft. of Bead (Col. 12 ÷ Col. 7) and Per Ft. of Joint	14 Electrode Cost/Ft. of Joint (Col. 9 × 8.5c)	15 Power + Electrode Cost/Ft. of Joint (Col. 13 + Col. 14)
3/16	1	3.75	7 5	15	.43	1.02	1.45
1/4	1 2	3 75 2.75	7.5 5.5	15 11	.52 .38 .90	2.2	3.1
3/8	1-3 4	3 75 2.75	7.5 5.5	15 11	.44 .38 1.7	4.5	6.2
1/2	1-5	3.75	7.5	15	.46 2.3	6.4	8.7

(C) CALCULATION OF LABOR COST (Cents):

Floor-to-floor Speed — Ft./Hr.	30	25	20	15	12	10	8		4	3	2
Labor Cost/ Ft. of Joint	3.33	4	5	6.66	8.33	10	12 5	16.7	25	33.3	50

Note: See explanation on Pages 224-225.

Finishing or Final Treatment—Finishing treatment includes such items as name plate, painting, sand blasting, stress relieving and heat treating. These not only enter into the total cost of the product as items of cost, but have an effect on the welding costs.

The name plate must be easily placed. Painting involves accessibility to surfaces to be painted, and this accessibility may be a matter of preparation. The same may be said of sand blasting in reference to preparation.

Stress relieving and/or heat treatment may mean special consideration in preparation and welding so as to avoid collapse or deformation when the metal is soft and provide support for escape of gases. Complete enclosure of parts should be avoided, otherwise the expansion of the air causes deformations. All of these must be given careful thought and their interrelation thoroughly studied.

This final treatment or finishing process may be related to preparation, the method of handling of joints or sub-assemblies, and these in turn effect the cost of welding.

Conclusions for Cost Reduction—Based on the foregoing and on the suggestions on Machine Design (Page 379)—

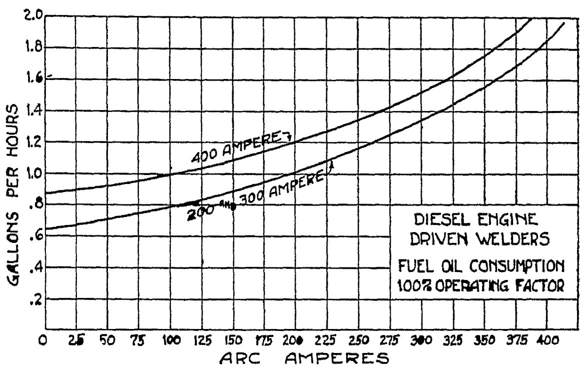
1. Changeover one part of a product at a time. See Page 406.
2. Design to meet functional requirements. Keep an open mind. See Page 379.
3. Don't try to duplicate in welded design the appearance of the conventional design. Proper design assures proper appearance. See Page 379.
4. Capitalize on the engineering freedom of welded design. Use combinations of various shapes and analyses of steels for minimum costs.
5. Select carefully the type of joint in light of available shop equipment. Scarfing costs are often more than offset by savings in welding costs.
6. Bending or forming generally is more economical than welding.
7. Proper fit-up of joints pays dividends by minimizing welding costs.
8. Sub-assembly costs can be reduced by proper design to minimize the amount of scarfing, fit-up and welding.
9. It pays to watch the size of members used as this affects not only material costs but welding costs.
10. Use of jigs and fixtures improves the operating factor for lower unit production costs.
11. Work positioners often increase welding speed for reduced labor cost.
12. Use the largest size electrode that is practical to minimize cost per foot of weld.
13. Take care in selection of electrodes to assure best possible performance economy.
14. Use the most modern, efficient generator possible so as to minimize power costs.
15. Minimize finishing costs by providing easy accessibility for painting, sand-blasting and name plate.
16. If heat treatment is used, take this into account when designing so as to prevent possible distortion or deformation.

COST CALCULATIONS FOR ENGINE DRIVEN WELDERS

Calculation of electrode and labor costs, for engine-driven welders, is the same as for motor-generator welders (see Pages 210-214). Different methods are used however for calculation of power costs. These methods of calculation of power or fuel costs are essentially the same for both Diesel and gasoline engine welders.

From suitable consumption curves (see Fig. 316) for a given "arc amperes", obtain the fuel consumption, at 100% operating factor. This, multiplied by the operating factor, gives the fuel consumption for arc time only. To this must be added the fuel consumption idling, which gives the total fuel consumption per hour. This, multiplied by the unit fuel cost, gives the power cost per hour. And divided by the production footage (arc speed x operating factor) gives the cost per foot for power.

Note that where an engine idles at reduced speed (see Fig. 316) there is a marked reduction in fuel consumption. For example, consider a 300 ampere unit at 250 arc amperes and 50% operating factor. Fuel consumption at 250 amperes is 2.46 gal. per hr. (from curve)—at 50% operating factor is 1.23 gal. per hr. Idling half-time at reduced speed, the engine consumes $\frac{1}{2}$ x .72 (from curve) or .36 gal. per hr. for a total of 1.59 gal. per hour. Power cost at 14¢ per gal. is 22.26 cents per hour This divided by production feet per hour is cost per foot for power.



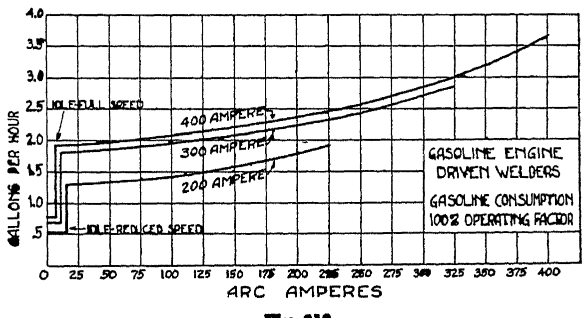


Fig. 316

Following is a form for tabulation of values and calculation:

FUEL CALCULATIONS

Gal. per hour at (from curve)......arc amperes..................
Gal. per hour at......% operating factor.........................
Gal. per hour idling (from curve)................................
Gal. per hours x % idling (1 minus % operating factor)..............
Total gal. per hour...............................
Fuel cost at........cents per gal..................................
Lubricating Oil*..........qts. at ....¢ ....
Total Fuel and Lubricating Oil Cost..............................
Production rate (Feet per Hour).................................
Fuel and Lubricant Cost per production foot........................

*Note—For gasoline driven welders, assume ½ pt. per hour lubricating oil. For Diesel engines, 1 qt. of lubricating oil to 5 gal. of fuel may be used as an average figure. (Lubricating oil consumption depends on condition of engine, and other factors such as temperature.)

MANUAL CARBON ARC WELDING

For many welding operations, not only on steel but on other metals, the hand carbon arc can be used to good advantage. For these applications a few hints on the proper procedure and currents to be used may be helpful.

Pointing of the Carbons.—The diameter of the point should be approximately half the diameter of the carbon used. The taper should be gradual back to the point where it is gripped in the holder.

Position of the Carbon in the Holder.—The carbon should be gripped as close to the arc as practical as, if a long length of carbon is exposed, the heating causes the carbon to vaporize and burn very rapidly, giving excessive wastage.

Polarity.—Electrode negative should be used in almost all cases.

Currents.—The proper current to be used depends upon the work to be done. The following table will serve as a guide. The currents given are about the maximum which should ever be used. Smaller currents may be used, depending upon the weight or thickness of the base metal.

MAXIMUM CURRENTS FOR HAND CARBON ARC

Size of Carbon Electrode	Maximum Current
5/32"	50
3/16"	100
1/4"	200
5/16"	350
3/8"	450
1/2"	700

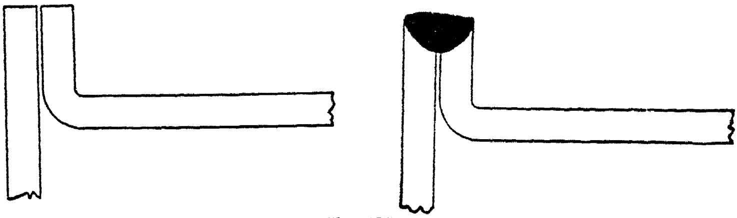


Fig. 317.

In making edge welds, Fig. 317, with the manual carbon arc, no metal is added. The edges are fitted close and fused together. This process can be used in many cases but where production warrants, the automatic shielded carbon arc should be used. For procedures and speeds in such cases, see Page 247.

The following tables gives average condition for welding.

Metal Thickness	Arc Volts	Arc Amp.	Carbon Size	Welding Speed Feet/Hour
16 ga.	25	90–100	3/16"	135
14	25	125–135	1/4"	125
12	25	200–250	1/4"–5/16"	110
10	25	250–275	1/4"–5/16"	100

PROCEDURE SPEED AND COST FOR AUTOMATIC WELDING WITH SHIELDED CARBON ARC

Shielding of the carbon arc for automatic welding is obtained by the introduction of three basically different types of autogenizers, namely: paste, fibrous, or powder. Each type is designed for specific applications.

Paste type autogenizers are mixed with water to a creamy consistency and applied to the seam either with a brush or automatically prior to welding. Its function is one of scavenging and forming a light protective layer of slag.

Fibrous autogenizer is used to stabilize the arc and produce a gas shielding. It is fed automatically past the carbon electrode about 1/4" above the tip, at a rate which will burn it completely several inches behind the carbon. Often both paste and fibrous autogenizers are used together. In this case the fibrous type produces the gas shielding and the paste acts as an additional fluxing and slag-protecting agent.

Powder autogenizers are fed automatically on the joint a few inches ahead of the electrode. The arc penetrates through the powder to produce the weld, leaving a protective layer of slag over the weld metal. The function of this powder is to purify and shield mechanically the molten metal.

The tables on the succeeding pages show where each autogenizer is used according to the type of joint and metal thickness.

The maximum speed and most economical welds can be obtained only when the welding procedure is correct and the quality of the base metal is the best suited for welding. The speeds included in the following tables are based on the welding of general purpose steels. (See Page 290 for analysis). When certain other types of steel of poorer arc welding quality are used it may be necessary to weld at speeds slower than those given in the tables.

The speeds given should not be taken as the actual limits. In many cases they may be increased from 50% to 100% by adhering to one or more of the following factors.

Proper control by management of best procedure, uniformity of materials (concerning variation in gauge), fit-up, clean seams, positioning, and steel specifications. Fixture design should be such that fit-up variables and arc disturbances are minimized. It should also meet requirements of specific applications in joint efficiency and pressure tightness.

In the following tabulations, the rate of welding is based on actual arc speed with no allowance for setting-up, fatigue, shop efficiency, etc.

The current given is approximate. There are various conditions that affect the amount of current needed—such as surface condition, amount of required build-up, and fit-up of the joint.

The data are based on a gap of not more than 10% of the plate thickness, but in no case more than $1/32''$ without backing or $1/16''$ with backing. If the gap without backing is greater than the above, seal with a small hand bead prior to welding. The offset of the edges should not exceed 10% of the metal thickness.

It is to be remembered that the arc voltage, current, speed of travel, type of autogenizer, amount of build up of bead may be changed independently of each other to meet specific applications without interference from any of the others.

The following is divided into *commercial* and *code welding* and the data are given only as a guide for welding procedures. Speeds and costs for the various types and thicknesses of joints may vary depending upon requirements. Each problem should be worked out in detail, and with care to take full advantage of all conditions.

COMMERCIAL WELDING

Material — plain carbon steel of good welding quality, see Page 290. The following procedure is intended for straight seams.

BUTT WELDS—Filler Metal Added—Work Clamped in Position on Copper Backing—Fibrous Flux. For this type of a weld a filler wire automatically fed into the arc is recommended, see Fig. 318. Used ing making tanks, range boilers, pipe and similar products.

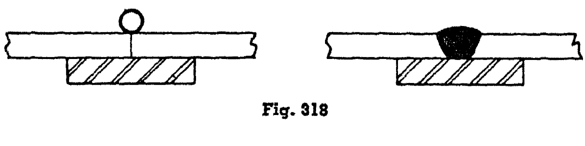


Fig. 318

Metal Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogen-izer	Filler Metal Lbs./Hr.	Welding Speed Ft./Hr.
16 ga.	33	280	5/16	Fibrous + Paste	3	125
14 ga.	34	340	5/16	Fibrous + Paste	3	120
12 ga.	34	350	5/16	Fibrous + Paste	3	110
10 ga.	35	375	5/16	Fibrous + Paste	4	95
3/16 in.	36	375	3/8	Fibrous + Paste	5	75
1/4 in.	37	400	3/8	Fibrous + Paste	5	60
5/16 in.	40	450	3/8	Fibrous + Paste	5	45

Where welds of higher quality are required the powdered autogenizer is used rather than the paste and fibrous types.

BUTT WELDS—Filler Metal Added—Work Clamped in Position on Copper Backing—Powdered Flux—See Fig. 318.

Metal Thick-ness	Arc Volts *	Arc Amps.	Carbon Size	Type Autogen-izer	Filler Metal Lbs./Hr.	** Angle	Welding Speed Ft./Hr.
3/16 in.	28–33	700	1/2	Powder	9.0	Horiz.	95
1/4 in.	28–33	750	1/2	Powder	9.0	Horiz.	85
5/16 in.	30–35	750	1/2	Powder	8.5	3	70
3/8 in.	30–35	750	1/2	Powder	7.5	3	45
1/2 in.	31–36	750	1/2	Powder	6.5	4	25

*When welding high tensile steels use the high side of the voltage range. A copper backing strip with a 1/4 x 1/16 groove is recommended when the metal thickness is 3/16 or more.
**When an angle is specified it indicates the angle of tilt from horizontal at the point of welding, so the welding progresses up the incline.

BUTT WELDS — No Filler Added—70% Average Penetration. The seams are tightly clamped together without backing. The joints may be prepared as shown in Figs. 319 or 320. Automobile axle housings,

motor and generator frames, ship channels and many other products may use this type of joint.

Fig. 319

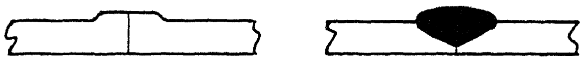


Fig. 320

Metal Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogenizer	Welding Speed Ft./Hr.
16 ga.	22	200	5/16	Paste	300
14 ga.	24	250	5/16	Paste	300
12 ga.	26	350	5/16	Paste	260
10 ga.	27	375	5/16	Paste	180
3/16 in.	35	400	3/8	Fibrous + Paste	150
1/4 in.	38	450	3/8	Fibrous + Paste	120
5/16 in.	38	450	3/8	Fibrous + Paste	100
3/8 in.	38	450	3/8	Fibrous + Paste	75

If the steel conforms closely to the recommended steel for good arc welding quality, the current recommended for 14 ga. to 3/16″ inclusive may be increased up to 450 amps. with a corresponding increase in welding speed.

BUTT WELDS—Filler Metal Added—70% Average Penetration. The tabulated data below is based on seams being tightly clamped together without backing. The use of filler wire automatically fed into the arc is recommended. This type of joint, Fig. 321 is somewhat stronger than those illustrated in Figs. 319 and 320 and is used on automobile torque tubes, railroad car center sills, etc.

Fig. 321

Metal Thickness	Arc Volts	Arc Amps	Carbon Size	Type Autogen-izer	Filler Metal Lbs./Hr.	Welding Speed Ft./Hr.
14 ga.	24	275	5/16	Paste	3	260
12 ga.	26	350	5/16	Paste	3	200
10 ga.	27	375	5/16	Paste	3	160
3/16 in.	36	400	3/8	Fibrous + Paste	5	140
1/4 in.	38	450	3/8	Fibrous + Paste	5	110
5/16 in.	38	450	3/8	Fibrous + Paste	5	90
3/8 in.	38	450	3/8	Fibrous + Paste	5	65

BUTT WELDS—Filler Metal Added—100% Penetration—Fibrous Autogenizer. This type of joint, Fig. 322 is welded from both sides without the use of backing. Filler metal may be rods tack welded on the seam, but filler wire automatically fed into the arc is recommended. If the application permits the omission of filler metal from one side the welding speed may be increased on that side and 50% of the filler metal saved. If the work is inclined about 5° from the horizontal, the welds can be made at the same speed as shown in the tabulation but the current can be reduced approximately 15% to 20%.

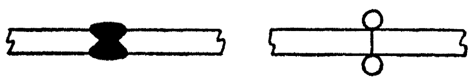


Fig. 322

This type of weld is used in the manufacture of pipe, pressure vessels and similar products where 100% penetration is necessary.

Metal Thickness	Arc Volts	Arc Amps	Carbon Size	Type Autogen-izer	Filler Metal Lbs./Hr.	Welding Speed Ft./Hr.
1/4 in.	34	350	3/8	Fibrous + Paste	6	50
5/16 in.	36	400	3/8	Fibrous + Paste	6	45
3/8 in.	38	450	3/8	Fibrous + Paste	6	40

BUTT WELDS—Filler Metal Added—100% Penetration—Powdered Flux—See Fig. 322.

Metal Thickness	Arc Volts	Arc Amps	Carbon Size	Type Autogenizer	Filler Metal Lbs./Hr.	Angle	Welding Speed Ft./Hr.
¼ in.	29-34	700	½	Powder	9.0	Horiz.	50
⅜ in.	30-35	750	½	Powder	9.0	Horiz.	50
½ in.	30-35	750	½	Powder	8.5	3	42.5
⅝ in.	31-36	750	½	Powder	7.5	3	35 0
¾ in.	32-37	700-750	½	Powder	6.5	6	22.5
⅞ in.	32-37	750-800	½	Powder	6.5	6	17.5
1	32-37	800-850	½	Powder	6.5	6	15.0

When welding high tensile steel use the high side of the voltage range. When an angle is specified it indicates the degree of tilt at the point of welding so the welding progresses up the incline. Powder is used rather than a paste and fibrous autogenizer when higher quality of weld metal is required.

Butt Welds in Heavy Plate—On plates thicker than 1″ the joint is prepared as in Fig. 323. Beads No. 1 and No. 2 are made without filler. Filler is added on passes No. 3 and 4, the filler being a hot rolled steel bar of sufficient size to fill the scarf. The welding is done on an angle of about 4° using the powdered type of autogenizer and 700 to 850 amperes.

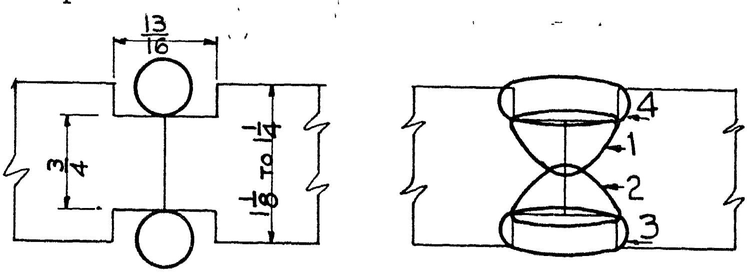


Fig. 323

LAP WELDS—No Backing—Work Clamped or Tacked in Place—No additional filler metal is required in making this type of weld. Fig. 324.

Fig. 324

Tanks, range boilers, ship and barge construction are some of the applications.

Plate Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogen-izer	Welding Speed Ft./Hr.
18 ga.	25	225	5/16	Paste	150
16 ga.	25	250	5/16	Paste	135
14 ga.	26	325	5/16	Paste	125
12 ga.	30	325	5/16	Fibrous + Paste	110
10 ga.	32	325	5/16	Fibrous + Paste	100
3/16 in.	33	325	3/8	Fibrous + Paste	90
1/4 in.	33	350	3/8	Fibrous + Paste	70
5/16 in.	35	400	3/8	Fibrous + Paste	50
3/8 in.	35	400	3/8	Fibrous + Paste	40

Note: If joint is tilted about 5° speeds may be increased as much as 50%.

Where the steel conforms closely to the recommended steel for good arc welding quality, the above currents may be increased about 75 amps. with a corresponding increase in welding speed.

Edge Welds.—The making of edge welds as illustrated in Fig. 325 requires no additional filler metal, the parts to be welded being simply fused together by the shielded carbon arc.

Metal Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogen-izer	Welding Speed Ft./Hr.
20 ga.	22	120	1/4	Paste	250
18 ga.	22	120	1/4	Paste	225
16 ga.	25	120	1/4	Paste	200
14 ga.	25	140	5/16	Paste	185
12 ga.	25	275	5/16	Paste	170
10 ga.	25	325	5/16	Paste	150
3/16 in.	25	350	5/16	Paste	140
1/4 in.	25	350	5/16	Paste	135

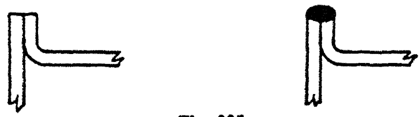


Fig. 325

Typical applications include mufflers, tanks, compressor housings, etc.

If the steel conforms closely to the recommended steel for good welding quality the above welding speeds may be increased two or three times with a corresponding increase in welding current providing the current does not exceed 450 amperes.

CORNER WELDS—The work should be clamped in place on a copper backing where 100% penetration is required. In cases where less penetration is required the backing may be omitted. No filler metal is required. See Fig. 326.

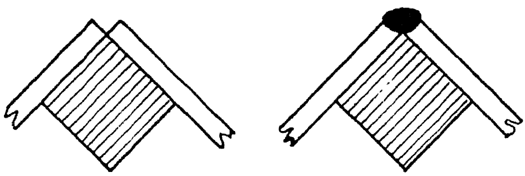


Fig. 326

Square tanks, street lighting standards and metal cabinets are typical examples of this application.

Metal Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogenizer	Welding Speed Ft./Hr.
18 ga.	24	120	1/4	Paste	130
16 ga.	24	135	1/4	Paste	130
14 ga.	24	150	1/4	Paste	130
12 ga.	25	275	5/16	Paste	115
10 ga.	32	325	5/16	Fibrous + Paste	100
3/16 in.	32	350	5/16	Fibrous + Paste	90

Building Up Shafts and Surfaces—Filler metal fed automatically into the arc is recommended for applying additional metal to round or flat surfaces as shown in Fig. 327. The speed of travel of the arc will determine the thickness of each layer of deposited metal. Welding at the speeds indicated below will produce a layer of weld metal which will machine-clean approximately 1/8″ thick.

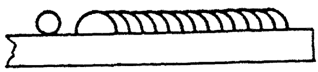


Fig. 327

Worn shafting, car wheels and similar items are built up for machining to original size by this method.

Shaft Size	Arc Volts	Arc Amps.	Carbon Size	Type Autogen-izer	Filler Metal Lbs./Hr.	Welding Speed Sq. In./Hr.
2½" to 6" dia.	30	250	5/16	Fibrous + Paste	8½	125
6" to 18" dia.	30	300	5/16	Fibrous + Paste	10	150
18" dia. and flat surfaces	32	300	5/16	Fibrous + Paste	14	200

CODE WELDING

A. S. M. E. U-68 or U-69

Material—Plain carbon steels which must successfully pass ASME homogeneity test.

Analysis: Carbon .10—.35%
Silicon .20 max.
Manganese .90 max.
Phos. .04 max.
Sulphur .05 max.

Some steels outside the above range can be welded satisfactorily at the speeds given below, however, in some cases it will be necessary to use lower speeds and currents in order to obtain satisfactory results. On the other hand, steels of good welding quality such as the General Purpose Steel, Page 290 may be welded at higher speeds. The following procedure is intended for straight seams.

BUTT WELDS—Filler Metal Added—100% Penetration—Powdered Flux.—Welding is done from both sides without backing. See Fig. 322.

Metal Thick-ness	Arc Volts	Arc Amps.	Carbon Size	Type Autogen-izer	Filler Metal Lbs./Hr.	Angle Degrees	Welding Speed Ft./Hr.
¼ in.	29–34	650	½	Powder	8.0	Horiz.	42.5
⅜ in.	30–35	650	½	Powder	8.0	1½	32.5
½ in.	30–35	600	½	Powder	6.5	3	22.5
⅝ in.	31–36	750	½	Powder	6.5	3	17.5
¾ in.	32–37	700	½	Powder	6.5	6	16.5

BUTT WELDS — Filler Metal Added — 50% Penetration Into Metallic Back-up Bead—

Metal Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogenizer	Filler Metal Lbs./Hr.	Angle Degrees	Welding Speed Ft./Hr.
¼ in.	29-34	650	½	Powder	8 0	Horiz.	85
⅜ in.	30-35	650	½	Powder	8.0	1½	65
½ in.	30-35	600	½	Powder	6.5	3	45
⅝ in.	31-36	750	½	Powder	6.5	3	35
¾ in.	32-37	700	½	Powder	6 5	6	33

When welding high tensile steel use the high side of the voltage range. The degree of angle indicates the angle of tilt from the horizontal at the point of welding, so the welding progresses up the incline.

HOW TO ESTIMATE COST OF MAKING WELDS AUTOMATICALLY WITH THE SHIELDED CARBON ARC

From the data given in the preceding pages, costs of welding the various types of joints and metal thicknesses can be readily secured.

The items used and necessary information are listed below.

Labor — The price of labor for automatic operators varies considerably due to existing conditions of location, etc. The figure used will be $1.00 per hour.

Power — Volts and amperes are given so that the amount of power is known. The efficiency of welders for carbon arc voltage requirements can be taken as an average of 60%. Figure power cost at $0.02 per K. W. H.

Electrodes—The life of a 13½" or 19½" carbon will vary from about ¾ to 3 hours depending upon various conditions. For a basis of estimating costs the carbon consumption will be figured at $0.10 per hour, since carbon cost per foot of welding is negligible.

Autogenizer—By consulting the tables it will be noted the type of autogenizer used.

Paste Type—Cost per pound is approximately $0.35 and one pound will cover an average of 300 feet of seam.

Fibrous—Cost per pound is approximately $0.30 and there are 60 feet in a pound. Assume the flux feeds at 8" per minute, which gives an average cost of $0.20 per hour.

Powder—Cost per pound is about $0.15 and is consumed at the rate of 8 to 20 pounds per hour. Based on the heaviest to the lightest thicknesses given (where powder is used), the amount will vary in proportion to the speed of travel, for a general cost figure.

Filler Metal—Cost per pound is approximately \$0.075. There are three different sizes used. The tables give the number of pounds per hour.

The number of feet per pound are as follows:

$\frac{3}{32}''$ diameter — 43.5 ft.
$\frac{1}{8}''$ " — 24.0 ft.
$\frac{5}{32}''$ " — 15.4 ft.

If closer cost-estimating is desired, consult manufacturer's price list for cost of particular items in quantity brackets purchased. Actual measurements may be taken of consumption of each item for a particular application.

The simplest way to figure direct costs is on an hourly basis and then allow for whatever efficiency factor for the particular application the shop uses. This may vary from 50% to 80%.

Example:—$\frac{3}{4}''$ Butt Weld A. S. M. E. U-68 and 69. Welding from both sides—no backing. Direct costs.

Metal Thickness	Arc Volts	Arc Amps.	Carbon Size	Type Autogenizer	Filler Metal Lbs./Hr.	Welding Speed Ft./Hr.
$\frac{3}{4}$ in.	34	700	$\frac{1}{2}''$	Powder	6.5	16.5

Direct cost—hourly basis

Labor @ \$1.00 per hour \$1.00

Power @ \$0.02 per KWH $\frac{700 \text{x} 34 \text{x} .02}{1000 \text{x} .60}$ .... .793

Carbon @ \$0.10 per hour .... .10

Autogenizer-Powder @ \$0.15/lb.–12x.15 .... 1.80

Filler Metal–$\frac{5}{32}''$ dia. @ \$0.075/lb.
6.5x.075 .... .49

Total cost 4.183

Cost per foot $\frac{4.183}{16.5}$ \$0.254

Note: The above method of figuring costs is based on actual arc time and does not take into consideration idle time or overhead.

PROCEDURE AND SPEEDS FOR AUTOMATIC WELDING WITH SHIELDED METALLIC ARC

The use of an automatic feeder of heavily coated metallic electrodes for welding with a shielded arc, as shown in Fig. 328, is practicable on many applications and particularly on butt joints in heavy plates, over $\frac{5}{8}''$ in thickness. Joints are prepared for welding in the same

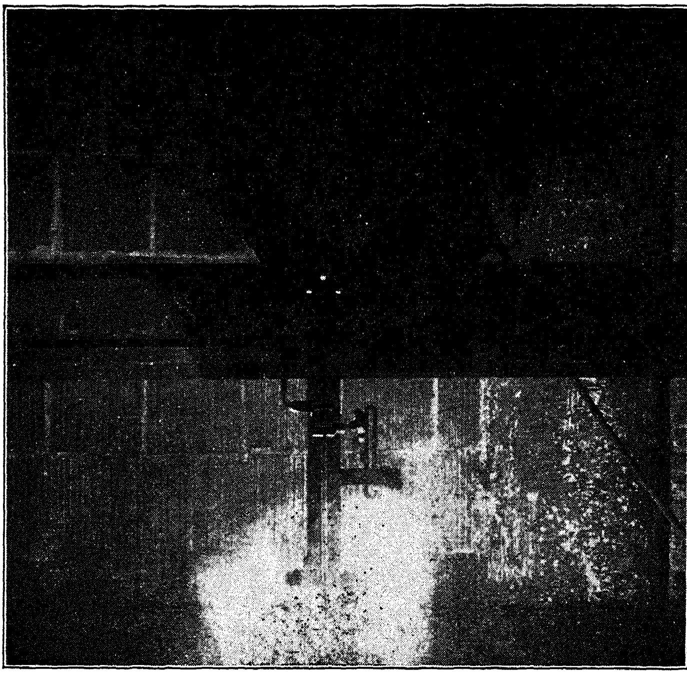


Fig. 328. Automatic feeder of metallic shielded arc electrodes in action.

manner as indicated for manual welding with shielded arc, see Figs. 207 to 211. Actual welding speeds will be approximately the same as for manual shielded arc welding; however, the total welding cost will be considerably less when an automatic feeder is used. In many cases of manual welding approximately 50% of the operator's time is consumed in actual welding, the balance being used to change electrodes, relieve fatigue, etc. With the use of the automatic feeder the human element in the actual welding operation is practically eliminated. Less concentrated physical effort is required and as a result approximately 80% of the operator's time is consumed in the actual welding. Thus it can be readily understood that about 60% more welding can be done per unit of time with the automatic feeder than by the manual process. The resultant cost per foot of weld will therefore be considerably less for the automatic feeder.

Also due to the automatic control of the welding conditions exceedingly uniform welds can be obtained.

HIGH SPEED WELDING

Occasionally it is desirable to weld at speeds higher than those usually used. This is true for both manual and automatic welding. Specific conditions have a large bearing on speed.

For manual operation, when the operator is sufficiently skillful and experienced, very high speeds may be obtained. This involves good

fit-up and clamping, the use of electrodes larger than usual, and higher currents. The quality of the joint may not be as high, but in a surprisingly large number of cases it is satisfactory. The consequent cost reduction is obvious.

For automatic welding, speeds as given in the tables may be increased up to 50% for commercial welds by adhering to one or more of the following factors:

Proper supervision by management as to adherence to procedure, uniformity of material, and steel specifications.

Best possible fixture which will eliminate variables of fit-up, arc blow, oil, foreign material from joint.

Weld requirements also govern the speed to a large extent.

As an example of what may be done, in case of automatic edge welds the current may be increased from 50% to 200% with speeds increased in approximately the same ratios.

SPEEDS AND COSTS FOR MANUAL WELDING WITH BARE OR WASHED ELECTRODES

On the following pages are charted in graph form the amounts of electrode required per foot of weld in making the common types of butt welds, lap and fillet welds, and corner welds in various thicknesses of metal. The actual welding speeds with no allowance for set-up of work, operator fatigue or other factors can also be obtained from the graph charts for the previously mentioned types of welds. The data contained in these graphs are based on use of correct welding procedure and proper fit-up of work to be welded in flat position. Speeds in other positions such as vertical and overhead will in general be somewhat slower.

From the information given in these graphs and in the following table, approximate welding costs can be estimated. However, it should be borne in mind that these speeds must be modified by a factor depending upon the time the welder actually welds.

Note: For purposes of calculation the following arc voltages may be used, for currents at mid range of those given. $\frac{1}{8}''$ electrode—20 volts. $\frac{5}{32}''$ electrode—21 volts. $\frac{3}{16}''$ electrode—22 volts. $\frac{1}{4}''$ electrode—22 volts.

Type of Weld	Thickness of Plate	Electrode Size	Current (amperes)
Plain Butt Weld 50% Penetration	1/8" 3/16" 1/4" 3/8"	1/8" 5/32" 3/16" 3/16"	75–125 110–185 150–225 150–225
Butt Weld, 60° Single Vee 100% Penetration	1/4" 3/8" 3/8" 1/2" 5/8"	5/32" 5/32" 3/16" 3/16" 3/16"	110–185 110–185 150–225 150–225 150–225
Butt Weld, 60° Double Vee 100% Penetration	3/8" 1/2" 5/8" 3/4" 1"	3/16" 3/16" 3/16" 3/16" 3/16"	150–225 150–225 150–225 150–225 150–225
Fillet or Lap Welds	1/8" 3/16" 1/4" 3/8" 1/2" 5/8"	5/32" 3/16" 1/4" 1/4" 1/4" 1/4"	110–185 150–225 190–275 190–275 190–275 190–275
Corner Weld	1/8" 1/4" 3/8" 1/2" 5/8"	5/32" 3/16" 3/16" 1/4" 1/4"	110–185 150–225 150–225 190–275 190–275
Edge Weld (work tilted 20° from horizontal; welding down slope)	18 ga. 16 ga. 14 ga. 12 ga.	1/4"* 1/4"* 1/4"* 1/4"*	80– 90 125 175–200 225–250

*Carbon electrode, no filler metal used.

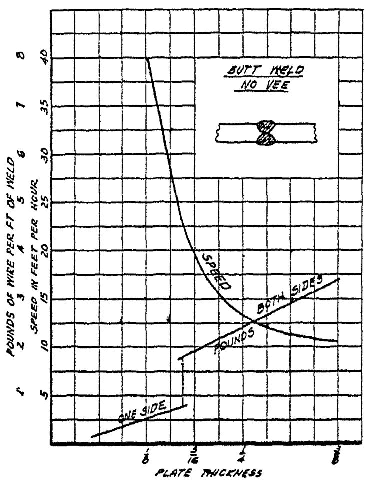


Fig. 329. Chart of welding speed and amounts of bare or washed electrodes for square groove butt weld.

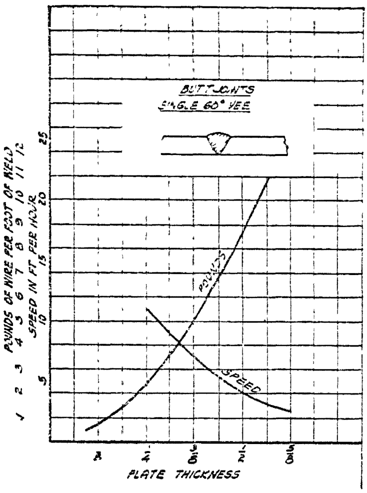


Fig. 330. Chart of welding speed and amounts of bare or washed electrodes for welding single vee groove butt joints.

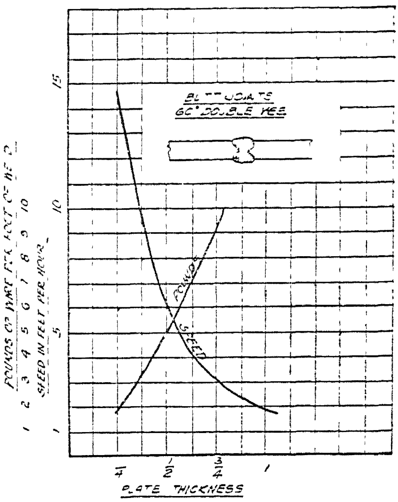


Fig. 331. Chart of welding speed and amounts of bare or washed electrodes for welding double vee groove butt joints.

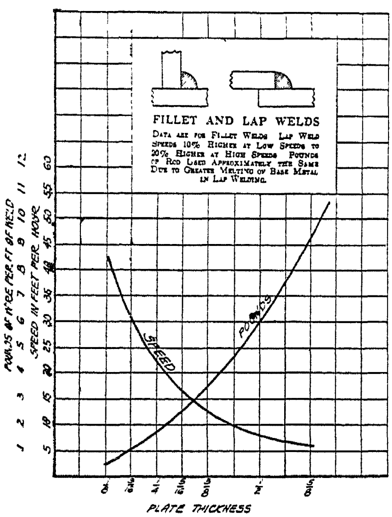


Fig. 332. Chart of welding speed and amounts of bare or washed electrode for fillet and lap welds.

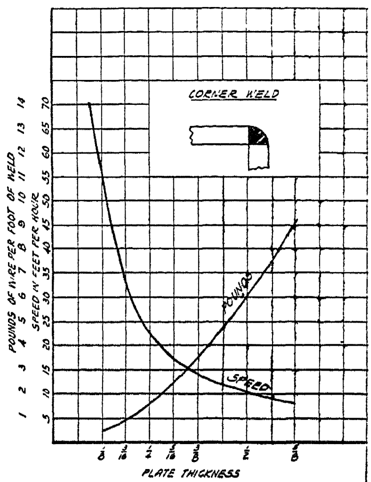


Fig. 333. Chart of welding speed and amounts of bare or washed electrode for corner welds.

PART IV

WELD METAL AND METHODS OF TESTING

Weld and Base Metal Structure
Physical Properties
Methods of Testing Weld Metals (A.W.S.)
Tensile Test
Free Bend Test
Guided Bend Test
Nick-Break Test
Impact Test
Specific Gravity Test
Fatigue Test
Radiographic Tests
Resistance to Corrosion

PART IV

WELD METAL AND METHODS OF TESTING

The metal structure and physical properties of welds and welded joints depend to a considerable degree upon the result of heat effects. The material welded, material used to produce the weld, procedure employed in making the weld and the type of arc welding process used, are also factors involved.

A comprehensive discussion from a metallurgical viewpoint would involve more space than is available. Only a basic discussion of this subject may be included in a book of this kind.

Weld Metal and Base Metal Structure

Since welding involves the use of heat, it is well to have in mind, certain basic thermal conditions as they exist during and after welding. This discussion herein refers to mild steel and the welding of mild steel.

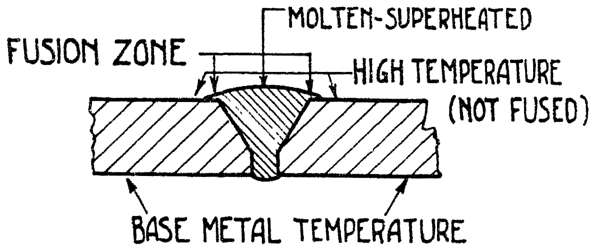


Fig. 334.

There is a great difference between the temperature of the parent metal (approximately air temperature) and that of the molten metal in the center of the weld. See Fig. 334. These variations in temperature may be shown by a temperature gradient curve such as in Fig. 335. This gradient, or the rate at which the temperature varies at different points depends upon these factors: (1) Rate of heat input to the welded joint. (2) Capacity of the base metal to absorb the heat, which in turn depends upon its temperature, heat conductivity, mass and specific heat.

The heat modifies the structure of the welded joint as a whole, including the base metal. It is to be noted however, these structural changes are sometimes interpreted improperly giving impressions which are not in accordance with the excellent physical performance of welded joints.

This excellent performance (see Page 262), results even though the joint (insofar as metal structure is concerned) is not uniform throughout and areas of different structure exist—such as the area in the base

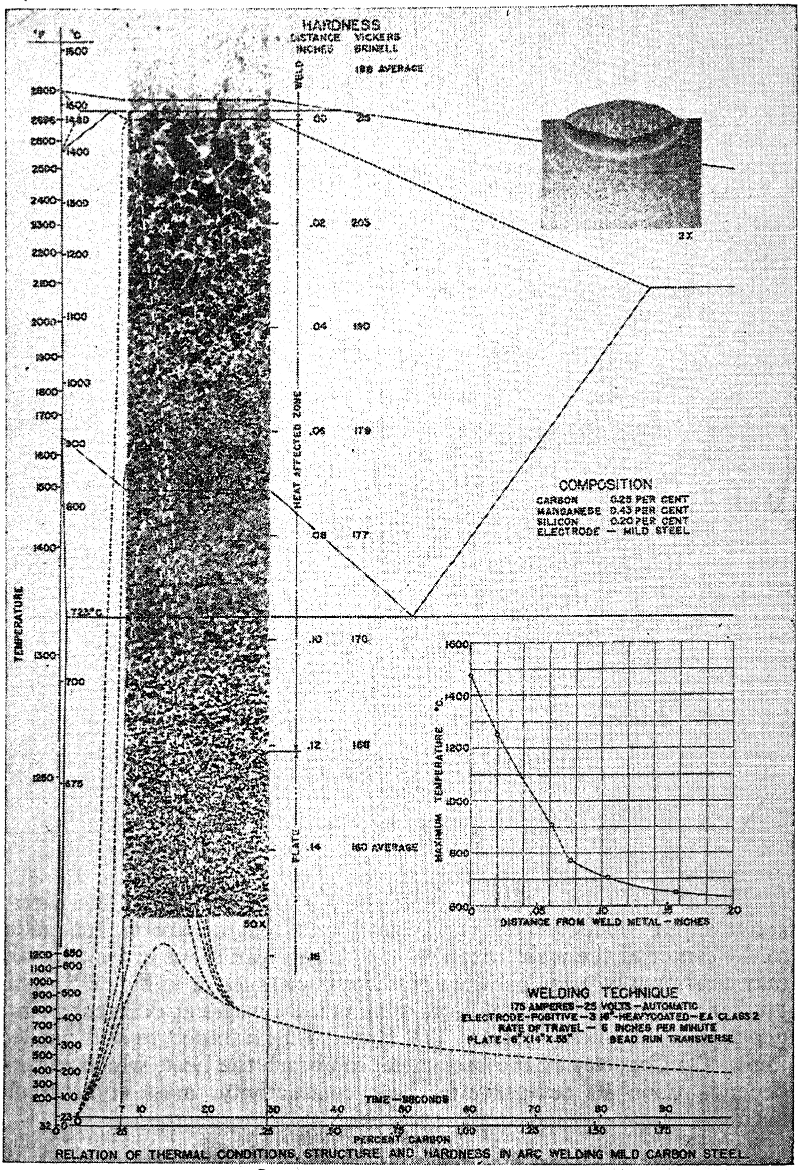


Fig. 335.

metal effected by the heat of welding, the fusion zone and the deposited metal. A joint in usual structural steel (low or medium carbon) when welded by suitable electrodes and correct procedure has physical properties superior to those of the base metal.

The relation of thermal conditions, structure and hardness of metal in arc welding mild carbon steel is shown in Fig. 335. Note that adjacent to the line of fusion there is a zone which has been heated to a temperature high enough to modify the micro structure. The extent of this change in structure depends upon the maximum temperature to which the metal is subjected, the length of time over which this temperature exists, the composition of the steel and the rate of cooling.

Deposition of a single bead of weld metal provides a simple demonstration of these changes in micro structure.

For the purpose of discussion and comparison of the different zones, the structure of the base metal is designated as normal. This structure varies greatly with steel-making practice, i.e., rolling temperature, plate thickness, etc.

From the normal structure of the base metal there is a gradual change to a zone of finer grain than the base metal. Note (Fig. 335) the structure of the base metal which has been heated above the lower critical temperature, (723° C) and below the upper critical temperature.

The cooling in this zone has been sufficiently rapid to result in this finer (than base metal) structure. From this zone, toward the deposited metal or weld is a zone which was subjected to a high temperature. In fact, it is the point at which the base metal reached its highest temperature. Note the gradual reduction in fineness reaching a maximum at the edge of weld. Adjacent to this last mentioned zone is the fusion zone and deposited metal.

It is true that by holding the base metal at an excessively high temperature for a long time, a structure of less than normal fineness results. However, due to the short time the metal is held at the high temperature and the quick rate of cooling, there results in a welded joint a greater strength and some increase in hardness as compared to the base metal.

In the case of a multiple pass weld, each bead has a refining action on preceding beads similar to the effect outlined above. The grain size of the metal depends upon the maximum temperature above the critical range to which the particular bead has been subjected and the length of time which it is held at this temperature. It should be noted however that the refining action caused by reheating of beads above the critical may not be uniform throughout the joint.

The speed of welding and the rate of heat input to the joint affects the degree of change in structure and hardness. On a given mass of parent metal, at a given temperature, a small bead deposited at high speed produces a greater hardening than one deposited at a greater rate of metal deposit and at a higher heat input per unit length of joint. This is because the small high-speed bead cools more rapidly than the larger high-heat bead.

The effect of welding heat determines to a great degree the weldability of a metal and its usefulness in fabrication. This effect depends on chemical composition—temperature to which the metal is heated, the length of time it is held at this temperature and the cooling rate from this temperature. Where the chemical composition is such that

the metal is sensitive to heat conditions or heat changes, as in the case of high carbon and some alloy steels the above conditions should be taken into account, and may require heat treatment both before and after welding. (See Page 287, Weldability.)

Tests show that a welded joint in usual structural steel (low or medium carbon) when welded by suitable electrodes and correct procedure has physical properties superior to those of the base metal, as evidenced by the fact that fracture occurs away from the welded joint and in the base metal. See Fig. 336.

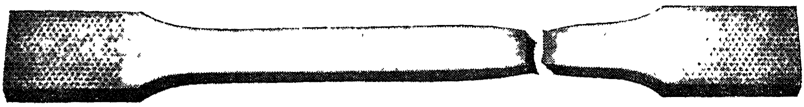


Fig. 336. Results of tensile strength test of weld made by shielded arc. Weld was machined flush with plate for equal cross sectional area of plate and weld. The specimen broke in the plate metal at a considerable distance from the weld.

This welded joint more than meets the most severe load requirements, efficiently and economically.

Comparative figures and results for various types of tests on weld metal and steel show this superiority most conclusively.

Physical Properties

The data are based on the work of the average welder with proper equipment, using proper procedure for the shielded arc process and also for the bare or washed electrodes. Study of these data and those given in Part III indicates why there has been a decided change to the use of the shielded arc process in welding.

The following tabulation is given, comparing deposited metal of shielded arc electrode and bare electrode to mild steel plate.

PROPERTIES OF WELD METALS AND MILD ROLLED STEEL

Material	Tensile Strength Lbs./Sq.In.	% Elongation in 2 Inches	Density Grams Per c.c.	Endurance Limit* Lbs./Sq.In.	Notched Bar Ft. Lbs.
Weld Metal, made with shielded arc	65,000–75,000	20–30	7.84–7.86	28,000–32,000	25–80 (Izod)
Mild Rolled Steel	55,000–65,000	20–30	7.86	24,000–28,000	20–80 (Izod)
Weld Metal, made with bare or washed electrode	40,000–55,000	5–10	7.5–7.7	12,000–15,000	8–15 (Izod)

*Maximum stress in outside fibres, 10 million reversals without failure. Rotating beam test. See Endurance Test, Page 280.

The above results are obtained by suitable tests devised to show relative mechanical and physical characteristics of the metals.

Method of Testing Weld Metal and Welded Joints

Following is the "Standard Methods for Mechanical Testing of Welds," prepared by the Committee of Standard Tests for Welds of American Welding Society.

FOREWORD

As for any engineering product, the quality of welds depends upon competent inspection and adequate tests. Experience has shown that, in general, mechanical tests to determine their strength and other properties are the least expensive and most reliable tests for the quality of welds. Therefore, they are the tests most widely used. In addition other tests are used in some cases. No other tests appear likely to replace mechanical tests entirely.

Mechanical tests for welds are similar to the usual mechanical tests for the base metal — plate, tubes, etc., with the changes which have been found necessary to determine the properties of welds. These tests for welds have now been used for a sufficient length of time to indicate quite definitely the properties to be determined and the test procedures which not only give adequate information as to the quality of the weld but are the most practicable for welded fabrications.

Although there is a surprising agreement among welding engineers on the properties to be determined and, in general, the test procedure, there is a wide divergence in the shape and size of the specimens and the details of the test procedure. This considerably increases the cost of making the tests, and decreases the usefulness of the results obtained under different codes and specifications, because they cannot be compared directly. There is no logical reason why for a particular welded fabrication the same size and shape of specimen and the same test procedure should not be used by every one. Standardization in this field has all the advantages to every one concerned that are so generally recognized in other fields and need not be discussed here.

Standardization of the mechanical tests for welds does not necessarily apply to research. It does apply to all tests during commercial production, i.e., what are often called "routine tests."

In preparing this standard no attempt has been made to promote the use of new or unused tests nor to elaborate the usual test procedure however desirable this might appear from a theoretical or logical viewpoint. These standards are the best compromise which could be found in the expectation that existing codes and specifications could be revised to comply with this standard with the least trouble and expense. If this standard cannot be used satisfactorily it is expected that changes may be necessary but that the changes will be consistent with this standard in so far as practicable. Compliance with this standard is strongly recommended in the conviction that such action will greatly benefit the welding industry.

GENERAL REQUIREMENTS

I. Scope

This standard gives the requirements for the specimens, the testing procedure and the method of obtaining the properties. It is not a specification promulgating required values of the properties. The persons including this standard as a portion of a code or specification for a welded product should state definitely:

1. The one or more tests which are required.

2. The limiting numerical values of the properties and whether they are minimum or maximum.

3. The interpretation, if any, of the properties.

II. Testing Procedure

All tests involving the application of a tensile load to a specimen shall be carried out in accordance with the applicable portions of "Standard Methods of Tension Testing of Metallic Materials," A.S.T.M. Designation E-8.

III. Nomenclature

The terminology used in this standard conforms to the "Standard Definitions of Terms Relating to Methods of Testing," A. S. T. M. Designation E-6, and to the standard of the AMERICAN WELDING SOCIETY, entitled "Welding and Cutting Nomenclature, Definitions and Symbols." The term "soundness" used in this standard means the degree of freedom of a weld from defects discernible by visual inspection of any exposed surface of weld metal. In preparing reports of tests made in accordance with this standard, nomenclature shall conform to the above standards and definitions.

IV. Etching

Specimens to be tested in accordance with this standard shall be etched for either of two purposes: (1) to determine the soundness of a weld (see Sec. VI,B), or (2) to determine the location of a weld.

For tests in which the dimensions of the specimen, the procedure or the results depend upon the location of the weld, the surface of the specimen at and adjacent to the weld shall first be etched with any reagent which makes the boundary between the weld metal and the base metal visible, if the boundary is not already distinctly visible.

NOTE: Some reagents commonly used for carbon steels and low-alloy steels (5% or less of alloying elements) are the following:

Hydrochloric acid — Equal parts by volume of concentrated hydrochloric (muriatic) acid and water. Immerse the welds in this reagent at or near the boiling temperature. Hydrochloric acid will etch satisfactorily on unpolished surfaces. It will usually enlarge gas pockets and dissolve slag inclusions, enlarging the resulting cavities.

Ammonium persulphate — One part of ammonium persulphate (solid) to nine parts of water by weight. Vigorously rub the surface of the weld with cotton saturated with this reagent at room temperature.

Iodine and potassium iodide — One part of powdered iodine (solid) to twelve parts of a solution of potassium iodide by weight. The solution should consist of one part of potassium iodide to five parts of water by weight. Brush the surface of the weld with this reagent at room temperature.

Nitric acid — One part of concentrated nitric acid to three parts of water by volume.

Caution — Always pour the acid into the water when diluting. Nitric acid causes bad stains and severe burns.

Either apply this reagent to the surface of the weld with a glass stirring rod at room temperature, or immerse the weld in boiling reagent provided the room is well ventilated. Nitric acid etches rapidly. It should be used on polished surfaces only, and will show the refined zone as well as the weld metal zone.

After etching, the weld should immediately be washed in clear water, preferably hot water; the excess water should be removed; the etched surface should then be immersed in ethyl alcohol, removed and dried, preferably in a warm air blast. The appearance may be preserved by coating with a thin clear lacquer.

DETAILS OF TESTS

V. Base Metal

If there are specifications for the base metal, the tests of the base metal shall be in accordance with these specifications.

If there are no specifications for the base metal, the tests of the base metal shall be carried out in accordance with the standards of the American Society for Testing Materials. Tensile tests, if any, shall be in accordance with "Standard Methods of Tension Testing of Metallic Materials," A. S. T. M. Designation E-8.

VI. Weld Metal

A. Density

1. *Specimen.* — The specimen, A, shall be a cylinder complying with the requirements of Fig. 1, and consisting entirely of metal from the deposited metal zone. If the size of the weld is insufficient, the specimen may be machined from a test plate complying with the requirements of Fig. 338.

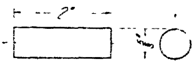


Fig. 337. Density specimen A

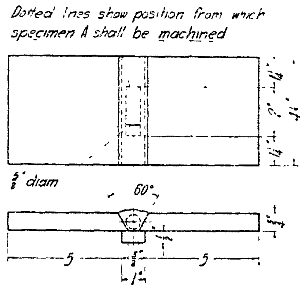


Fig. 338. Test plate for density specimen A.

2. *Procedure.* — After the specimen has been subjected to room temperature for not less than two hours, the average dimensions shall be measured (screw micrometer) to the nearest 0.0001 inch and the room temperature in degrees Centigrade shall be determined. Using a balance having an error not exceeding 0.0001 gm., the weight of the specimen in air shall be determined.

3. *Results.* — The density shall be computed using the formula:

Density, in grams per cubic centimeter =

$$\frac{\text{weight in air, in grams}}{\text{volume in cubic inches} \times (1 - 0.000033 \times t) \times 16.3872}$$

in which

t = temperature of specimen in degrees Centigrade.
16.3872 = number of cubic centimeters in one cubic inch.
0.000033 = volumetric coefficient of expansion of ferrous weld metal per degree Centigrade.

NOTE: The density is not an accurate measure of the soundness of weld metal. Voids or slag inclusions scattered throughout the metal abundantly enough so that on an average straight line scribed on the face of the metal, one-twentieth of the length strikes voids, would result in a change in density of $(1/20)^3$ or one in 8000 (.012%). To detect such a change calls for high accuracy of measurement. A further difficulty rises from the fact that the normal variations in density between different lots of sound steel may be themselves much greater than one in 8000.

B. Soundness: Etch Test[1]

1. *Specimen.* — A portion of the joint, specimen B (no figure) displaying a complete transverse section of the weld shall be removed by any convenient means such as trepanning, flame cutting, drilling or sawing. If removed by flame cutting at least 1/8 inch shall be machined from the face that sections the weld. This face shall be smooth, bright, and polished.

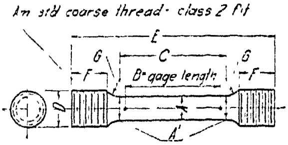
NOTE: The face may be filed and polished with abrasive cloth finishing with grade 00.

[1] See also Sections VIIA and VIIIA.

2. *Procedure.* — The face shall be etched. (See Note, Section IV, for suggested etching reagents.)

3. *Results.* — The etched transverse section of the weld shall be examined for soundness. (See Sec. III.)

> NOTE: Persons writing codes or specifications should state definitely their requirements for soundness. Typical requirements are: "complete penetration," "no inclusions," "the number of gas pockets shall not exceed——per square inch," "no gas pocket shall exceed——inches in its greatest dimension," etc.



Dimensions

Specimen	$A^{(2)}$	$Area^{(1)}$	B	$C^{(3)}$	D	$E^{(4)}$	$F^{(4)}$	$G^{(3)}$
	in	sq in	in	in	in	in	in	in
C-1	0.505	0.200	2	2 1/4	3/4	4 1/4	3/4	3/8
C-2	.437	.150	1 3/4	2	5/8	4	3/4	3/8
C-3	.357	.100	1.4	1.65	1/2	3 1/4	5/8	1/4
C-4	.252	.050	1	1 1/4	3/8	2 1/2	1/2	3/16
C-5	.126	.0125	1/2	3/4	1/4	1 5/8	3/8	3/32

A' = (A min, 1.01A max)

(1) Cross-sectional area = $0.785 A^2$

(2) Tolerance, ±1%

(3) Approximate

(4) Minimum

Note: Dimensions A, B, C and G shall be as shown, but the ends may be of any shape to fit the holders of the testing machine in such a way that the load shall be axial.

Fig. 339. Weld-metal tensile specimens C-1 to C-5, inclusive.

C. *Tensile Strength*

1. *Specimen.* — The specimen, C-1, C-2, C-3, C-4 or C-5, shall comply with the requirements of Fig. 339 for the specimen having the largest diameter which can be machined from the welded joint. The portion of the specimen included in the gage length *B* shall consist entirely of metal from the deposited metal zone. The diameter at the ends of the reduced section shall be not less than the diameter at the middle and shall not exceed 101% of the diameter at the middle. All of these specimens are geometrically similar in all significant dimensions, therefore the properties determined from any one of them are approximately the same as the properties determined from any other one, so far as testing technique is concerned.

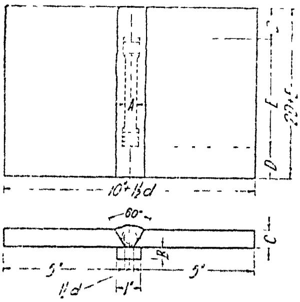
In the event that filler metal is to be deposited specifically for the purpose of this test, a test plate complying with the requirements for specimen C-1, Fig. 340, shall be used, unless the subsize test plate for specimen C-4, Fig. 340, is specifically called for in the specifications. The apparatus, materials, methods and rate of depositing the weld metal in the test plate shall, so far as practicable, be the same as those used in making welds with the given filler metal.

> NOTE: Due to unavoidable differences in the method of depositing the filler metal and in rates of cooling, the properties of the weld metal determined from a specimen will depend upon the dimensions of the adjacent metal.

For thermit welds a suitable refractory material shall be used for a trough in which the weld metal is to be allowed to solidify.

2. *Procedure.* — The diameter of the specimen at the middle of the reduced section shall be measured in inches and the gage length defined by a gage mark at each end. The specimen shall be ruptured under tensile load, and the maximum load in pounds shall be determined.

3. *Results.*—The tensile strength shall be obtained in pounds per sq. in., by dividing the maximum load by the cross-sectional area of the specimen at the middle. The cross-sectional area of the specimen shall be obtained by squaring the diameter of the specimen and multiplying by 0.785. The elongation shall be determined by removing the specimen from the machine, fitting the fractured ends of the specimen together, measuring the distance between the gage marks and subtracting the gage length. The per cent elongation shall be obtained by dividing the elongation by the gage length and multiplying by 100.



d=diameter of filler metal (welding rod or electrode)
Dotted lines show position from which specimen shall be machined

Specimen	d in	A in	B in	C in	D in	E in	2D+E in
C1	>5/32	0.505	1/2	3/4	1¼	4½	7
C1	5/32	.505	1/4	3/4	1¼	4½	7
C4	<5/32	.252	1/4	3/8	1 3/16	2 5/8	5

Note: Test plate may be lengthened as desired to provide for more than one specimen.

Fig. 340. Test plate for weld-metal tensile specimen C-1 or C-4.

VII. Butt-Welded Joints

General Statement: Individual specifications may designate which of the specimens described in this section shall be used, and the order in which they shall be cut from any prepared plate or pipe sample. No weld in a plate sample shall be begun or ended nearer than one inch to any portion of a welded specimen taken from that plate.

A. *Soundness: Nick-Break Test*

1. *Specimen.* — For a butt weld in plate, the nick-break specimen, *D-1*, shall comply with the requirements of Fig. 341.

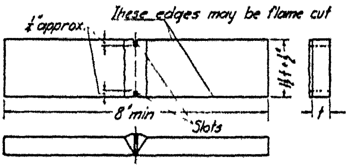


Fig. 341. Nick-break specimen D-1 (plate).

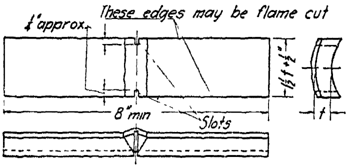


Fig. 342. Nick-break specimen D-2 (pipe).

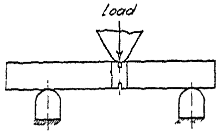


Fig. 343. Method of rupturing nick-break specimens.

For a butt weld in pipe or tubing the nick-break specimen, *D*-2, shall comply with the requirements of Fig. 342.

2. *Procedure.* — The specimen shall be supported substantially in accordance with Fig. 343 and ruptured by a force which, unless otherwise specified, may be applied either slowly or suddenly as by one or more blows of a hammer.

NOTE: A sharp sudden heavy blow is often specified. There appears to be but little evidence to indicate that there is any appreciable difference in the appearance of the fractured surface caused by a difference in the rate of applying the force.

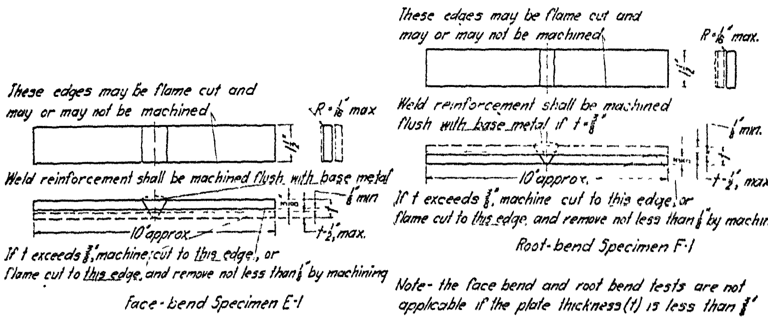


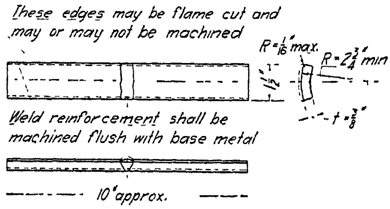
Fig. 344. Face- and root-bend specimens E-1 and F-1 (plate).

3. *Results.* — The surfaces of the fracture shall be examined for soundness. (See Sec. III and Note, Sec. VI, *B* 3.)

B. Soundness: Guided-Bend Test

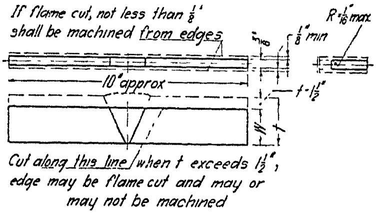
1. *Specimens.* — For welded butt joints in plate, the face-bend specimen, *E*-1, and the root-bend specimen, *F*-1, shall comply with the requirements of Fig. 344.

For welded butt joints in pipe or tubing, the face-bend specimen, *E*-2, and the root-bend specimen, *F*-2, shall comply with the requirements of Fig. 345.



Note: This test as now specified is intended for pipe of 3/8-inch nominal wall thickness only, and is not considered suitable for pipe having a nominal diameter of less than 6 inches.

Fig. 345. Face- or root-bend specimens, E-2 or F-2, resp. (pipe).



t, in	W, in
¾" to 1½"	t
> 1½"	1½"

Note: The side-bend test is not applicable if the plate thickness (t) is less than ¾

Fig. 346. Side-bend specimen G.

The side-bend specimen, G, shall comply with the requirements of Fig. 346. Tool marks, if any, shall be lengthwise of the specimen.

NOTE: Tests have shown that the severity of the guided-bend test increases to some extent with increasing width/thickness ratio of the specimen. Results of the side-bend test are therefore not directly comparable when obtained on specimens G, Fig. 346, having different widths W.

2. *Procedure.* — Each specimen shall be bent in a jig substantially in accordance with Fig. 347. Any convenient means may be used for moving the male member with relation to the female member.

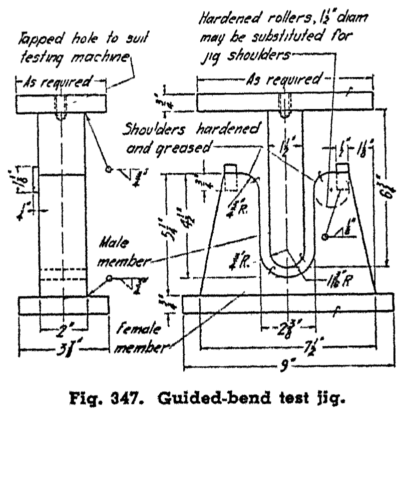


Fig. 347. Guided-bend test jig.

The specimen shall be placed on the female member of the jig with the weld at midspan. The two members of the jig shall be forced together until the curvature of the specimen is such that a 1/32 inch diameter wire cannot be passed between the curved portion of the male member and the specimen. The specimen shall then be removed from the jig.

Face-bend specimens, *E*-1 and *E*-2, shall be placed on the female member of the jig with the face of the weld directed toward the gap.

Root-bend specimens, *F*-1 and *F*-2, shall be placed on the female member of the jig with the root of the weld directed toward the gap.

Side-bend specimen, G, shall be placed on the female member of the jig with that side showing the greatest defects, if any, directed toward the gap.

3. *Results.* — The convex surface of the specimen shall be examined for the appearance of cracks. Any specimen in which a crack is present after the bending, exceeding a specified size measured in any direction, shall be considered as having failed. Cracks occurring at the corners during testing shall not be considered.

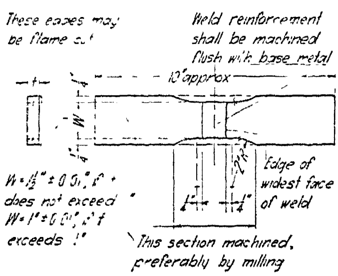


Fig. 348. Tensile specimen H-1 (plate).

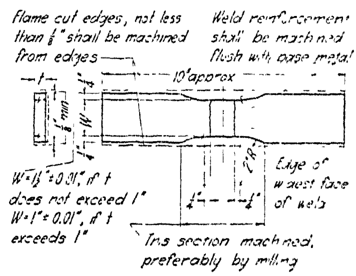


Fig. 349. Tensile specimen H-2 (plate).

C. *Tensile Strength*

1. *Specimens.* — For a welded butt joint in plate, the specimen shall comply with the requirements of Fig. 348, specimen *H*-1, unless in the code or specifications the requirements of Fig. 349, specimen *H*-2, are specifically called for.

> NOTE: These two specimens differ only in that in specimen *H*-2 flame cutting of the specimens along the edges is permitted only if followed by machining to a depth of at least 1/8 inch to remove the flame-affected material.

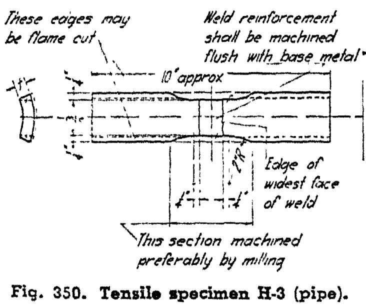


Fig. 350. Tensile specimen H-3 (pipe).

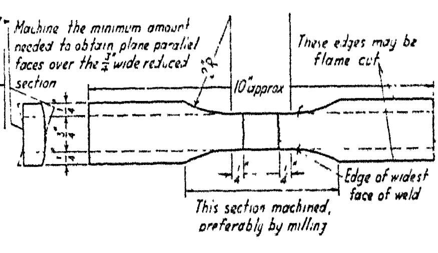


Fig. 351. Tensile specimen H-4 (pipe).

For a circumferentially-welded butt joint in pipe or tubing having a nominal diameter exceeding 2 inches, either specimen *H*-3 or *H*-4 may be used as called for in the code or specification. Specimen *H*-3 shall comply with the requirements of Fig. 350. The ends of the specimen may either be flattened by any suitable means or the ends may be placed in the grips of the testing machine without flattening. Specimen *H*-4 shall comply with the requirements of Fig. 351. This specimen is not recommended for wall thicknesses less than 3/8 inch nominal.

For circumferentially-welded butt joints in pipe or tubing having a nominal diameter not exceeding 2 inches, the specimen *H-5* (full section specimen) shall comply with the requirements of Fig. 352.

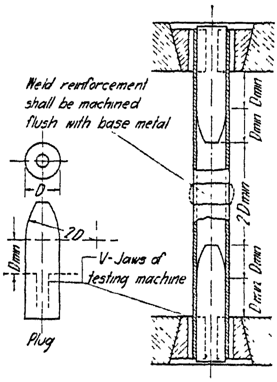


Fig. 352. Tensile specimen H-5 (pipe).

2. *Procedure.* — For specimens *H-1*, *H-2*, *H-3* and *H-4*, the least width and corresponding thickness of the reduced section shall be measured in inches. For specimen *H-5*, the average outside diameter, *OD*, either at the weld or at a distance not exceeding ½ inch from the boundary between the base metal and the weld metal, and also the average inside diameter, *ID*, of the base metal at either end of the specimen shall be measured in inches. The specimen shall be ruptured under tensile load and the maximum load in pounds shall be determined.

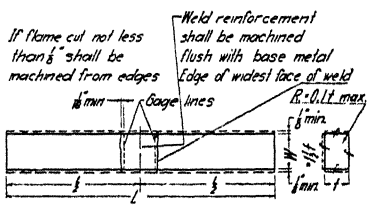
3. *Results.* — The cross-sectional area shall be obtained as follows:

Specimen	*Cross-Sectional Area* =
H-1, *H-2*, *H-3* or *H-4*	width × thickness
H-5	0.785 (OD^2 — ID^2)

The *tensile strength* in pounds per sq. in. shall be obtained by dividing the maximum load by the cross-sectional area.

D. Ductility: Free-Bend Test

1. *Specimen.* — For butt-welded joints in plate, the specimen, *J-1*, shall comply with the requirements of Fig. 353.



Dimensions

t, in.	1/4	3/8	1/2	5/8	3/4	1	1 1/4	1 1/2	2	2 1/2
W, in	3/8	9/16	3/4	15/16	1 1/8	1 1/2	1 7/8	2 1/4	3	3 3/4
L min, in	6	8	9	10	11	12	13 1/2	15	18	21
B* min, in	1 1/4	1 1/4	1 1/4	2	2	2	2	2	2	3

*See fig. 18

Note:- the length L is suggestive only, not mandatory

Fig. 353. Free-bend specimen J-1 (plate).

Note: If desired, the edges of this specimen may be prepared by machine flame cutting, followed by rounding of the corners with a file. If flame cut specimens fail, additional specimens with edges finished by machining may be tested, two for each flame cut specimen which fails. Each of these specimens must pass the test.

For a circumferentially-welded butt joint in pipe or tubing, the specimen, J-2, shall comply with the requirements of Fig. 354.

In both cases the width shall be 1.5 multiplied by the thickness of the specimen. Each corner lengthwise of the specimen shall be rounded in a radius not exceeding 1/10 the thickness (t) of the specimen. Tool marks, if any, shall be lengthwise of the specimen.

If the line between the weld metal and the base metal is not distinctly visible when the specimen is ready for testing, the surface of the specimen shall be etched with a suitable reagent.

2. *Procedure.* — *Gage Lines:* The gage lines shall be lightly scribed on the face of the weld. The gage length (distance between gage lines) shall be approximately 1/8 inch less than the width of the face of the weld, and shall be measured in inches to the nearest 0.01 inch.

For single groove welds, the gage lines shall be on the wider face of the weld.

For double groove welds, the gage lines on one-half the specimens shall be on one face of the weld, and on the other half of the specimens, on the other face.

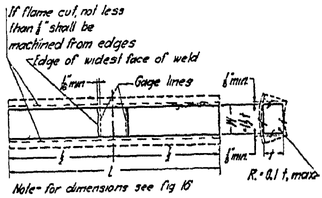


Fig. 354. Free-bend specimen J-2 (pipe).

Note: If desired, the edges of this specimen may be prepared by machine flame cutting, followed by rounding of the corners with a file. If flame cut specimens fail, additional specimens with edges finished by machining may be tested, two for each flame cut specimen which fails. Each of these specimens must pass the test.

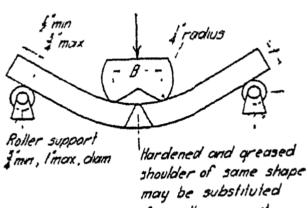


Fig. 355. Initial bend for free-bend specimens.

Initial Bend: Each specimen shall be bent initially by the use of a fixture complying with the requirements of Fig. 355. The surface of the specimen containing the gage line shall be directed toward the supports. The weld shall be at midspan of both the supports and the loading block.

Alternate Initial Bend: If the purchaser and the vendor agree, the initial bend may be made by holding each specimen in the jaws of a vise with one-third the length of the specimen projecting from the jaws, then bending the specimen away from the gage lines through an angle of from 30 to 45° by blows of a hammer. The other end of the specimen shall be bent in the same way.

In order that the final bend shall be centered on the weld, the initial bends shall be symmetrical with respect to the weld, and both ends shall be bent through the same angle.

Final Bend: Compressive forces shall be applied to the ends of the specimen, continuously decreasing the distance between the ends, substantially in accordance with Fig. 356.

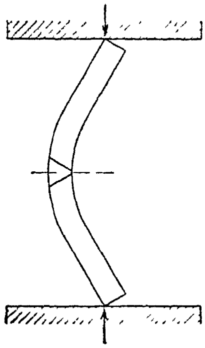


Fig. 356. Final bend for free-bend specimens.

NOTE: Any convenient means, such as a vise or a testing machine, may be used for the final bend. The use of a fixture complying with Fig. 357 is recommended. It prevents the ends of the specimen from slipping as it is bent. Life and property may be endangered if the specimen slips.

When either a crack or a depression exceeding a specified size in any direction appears on the face of the weld, the load shall immediately be removed. If no crack appears, the specimen shall be bent double. Cracks occurring on the corners of the specimen during testing shall not be considered.

3. *Results.* — The elongation shall be determined by measuring the minimum distance between the gage lines, along the convex surface of the weld, to the nearest 0.01 inch and subtracting the initial gage length. The per cent *elongation* shall be obtained by dividing the elongation by the initial gage length and multiplying by 100.

NOTE: A flexible steel scale graduated in hundredths of an inch and a magnifying glass may conveniently be used when determining the elongation.

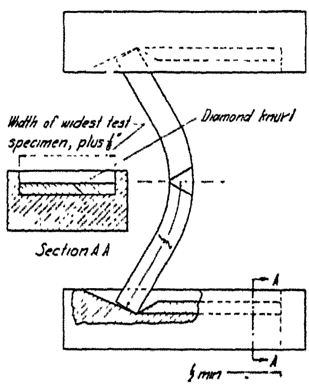


Fig. 357. Recommended fixture for final bending of free-bend specimens.

VIII. Fillet-Welded Joints

A. *Soundness: Fillet-Weld-Break Test*

1. *Specimen.* — The fillet-weld-break specimen, K, shall comply with the requirements of Fig. 358.

2. *Procedure.* — A force, A, shall be applied to the specimen substantially in accordance with Fig. 359, until rupture of the specimen occurs. The force may be applied by any convenient means.

NOTE: A press, a testing machine, or blows of a hammer, may be used.

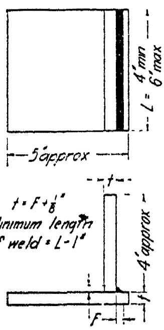


Fig. 358. Fillet-weld-break specimen K.

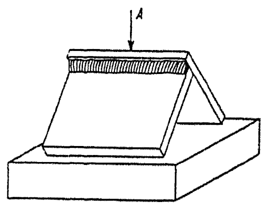


Fig. 359. Method of rupturing fillet-weld-break specimen K.

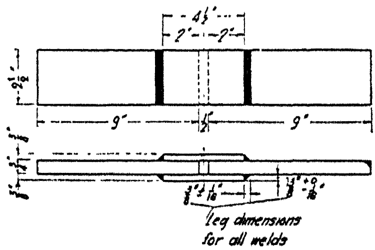


Fig. 360. Transverse fillet-weld shearing specimen L-1.

3. *Results.* — The surfaces of the fracture shall be examined for soundness. (See Sec. III and Note Sec. VI, B 3).

B. *Shearing Strength: Transverse Welds*

1. *Specimens.* — *Type A:* The transverse fillet-weld specimen, L-1, shall comply with the requirements given in Fig. 360.

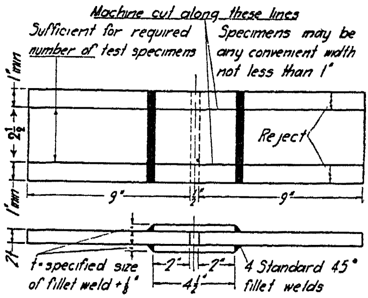


Fig. 361. Transverse fillet-weld shearing specimen L-2.

Type B: The transverse fillet-weld specimen, *L*-2, shall comply with the requirements of Fig. 361.

NOTE: These two types of specimen are currently used for shear tests of fillet welds; type *A*, where comparative rather than absolute value of strength per linear inch of fillet weld is sufficient, and where because of cost or of time limitations it is desired to avoid machining of specimens; and type *B*, where more nearly exact values are desired.

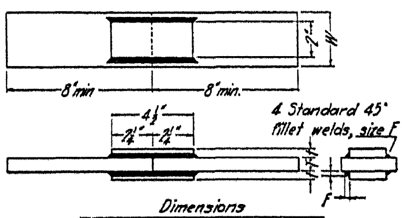
2. *Procedure.* — The width of the specimen shall be measured in inches. The specimen shall be ruptured under tensile load, and the maximum load in pounds shall be determined.

3. *Results.* — The shearing strength of the welds in pounds per linear inch shall be obtained by dividing the maximum force by twice the width of the specimen.

The shearing strength of the welds in pounds per square inch shall be obtained by dividing the shearing strength in pounds per linear inch by the average throat dimension of the welds in inches.

C. *Shearing Strength: Longitudinal Welds*

1. *Specimen.* — The longitudinal fillet-weld specimen, M, after welding shall comply with the requirements of Fig. 362 and after machining shall comply with the requirements of Fig. 363.



Dimensions

Size of weld F, in.	1/8	1/4	3/8	1/2
Thickness t, in.	3/8	1/2	3/4	1
Thickness T, in.	3/8	3/4	1	1 1/4
Width W, in.	3	3	3	3 1/2

Fig. 362. Longitudinal fillet-weld shearing specimen M after welding.

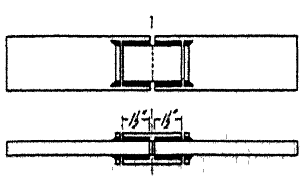


Fig. 363. Longitudinal fillet-weld shearing specimen M after machining. Note—For other dimensions see Fig. 362.

2. *Procedure.* — The length of each weld shall be measured in inches. The specimen shall be ruptured under tensile load, and the maximum force in pounds shall be determined.

3. *Results.* — The *shearing strength* of the welds in pounds per linear inch shall be obtained by dividing the maximum force by the sum of the lengths of the welds which ruptured.

In the order given, these "Standard Methods of Mechanical Testing of Welds" may be further discussed and illustrated. A discussion of these as well as other different methods of testing follows.

In order to secure accurate comparative results, conditions must be the same for all samples and tests. Inasmuch as field conditions vary, it is advisable to make all tests under laboratory conditions with well defined and controlled procedures.

Density—Read carefully the note on Page 265. On the comparative basis discussed, shielded arc deposit has a density equal to steel.

Etch Test—This is a test for soundness which is occasionally used. Other methods, such as nick-break are more generally used, due to the simplicity and ease of procedure.

Tensile Test—A specimen prepared as indicated in Fig. 340 is placed in a tensile testing machine, (see Fig. 364) and subjected to a tensile or pulling load. In addition to the tensile strength and elongation mentioned in the Standards, the yield point may be determined by observing the dial. This is done by applying the load at a steady rate of increase. When the yield point is reached there is a sudden halt of the load-indicating pointer. The load at this point is recorded and the corresponding stress is taken as the yield point.

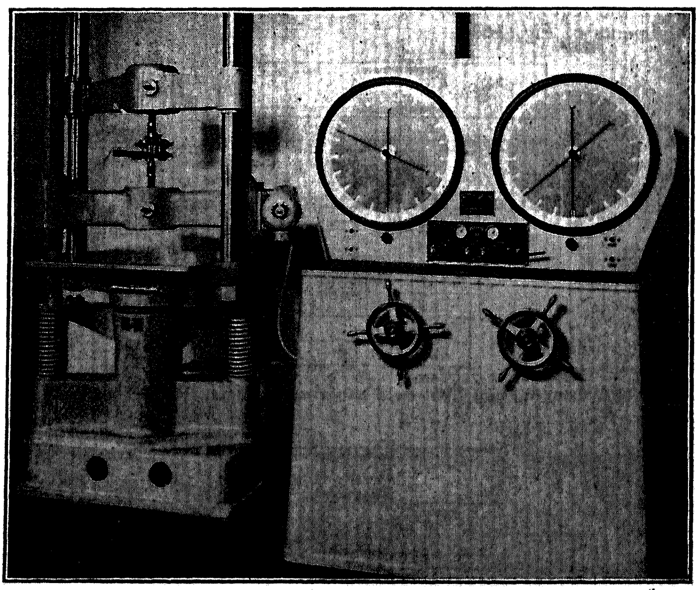


Fig. 364. Tensile testing machine.

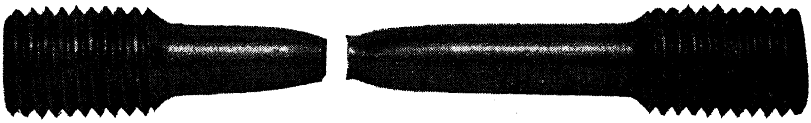


Fig. 365. Typical tensile test specimen of shielded arc weld metal showed tensile strength of 76,100 lbs. per sq. in.; elongation in 2" of 25.8%; reduction in area of 48%.

Reduction of area may also be determined by holding the pieces of the fractured specimen together in a vise and measuring the average diameter of the smallest cross section with a micrometer, fitted with points so shaped that they will come in contact with the specimen at its smallest diameter. The reduction in area is calculated as the percentage reduction based on the original area. Note the reduction of area as shown in the specimen of Fig. 365. Careful observation of the broken section will show a ridge or rim around one piece. This is known as cupping and it is measured in per cent of complete rim—100% or full cup. High values are desirable. Note the full cup in the specimen of Fig. 365.

Nick-Break Test—This test, simple and inexpensive to make, will disclose the soundness of weld metals. A nick-break test specimen is prepared by welding two plates together, cutting out a section as explained, Page 267, and nicking it on each side with a saw. When struck with sufficient force, the specimen will break at the nicks, exposing the metal for examination.

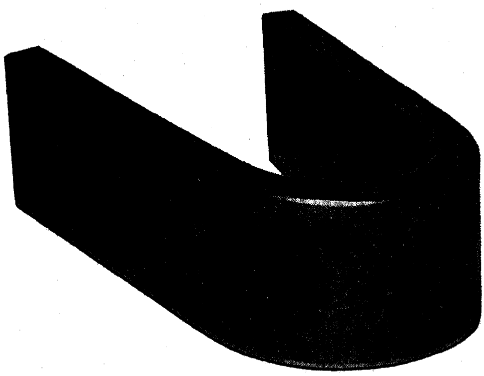


Fig. 366. A guided-bend test specimen.

Guided Bend Test—Soundness—This test which is for soundness is rather severe. It requires inexpensive samples and equipment. Welded joints made with shielded arc, with proper equipment and procedure, easily pass this test. It is coming to be one of the most frequently and generally used because of its low cost, ease of making and critical requirements. A typical test specimen is shown in Fig. 366.

Tensile Strength—Joints—The tensile specimen is prepared as directed in the Standards. Test results as outlined under Tensile Tests for weld metal may be obtained. The same general remarks apply to this section as given under Tensile Test for Weld Metal.

Free Bend Test—Ductility—This is another simple and inexpensive test. It indicates the elongation and compression of the metal in a welded joint.

Tests of welded joints made in this manner indicate the high ductility of weld metal produced by the shielded arc. Such weld metal shows elongation of 25% to 40%, and in some cases much more (see Fig. 376), as compared with only 15% to 25% for welds produced with bare or lightly coated electrode.

A free-bend specimen made in 1½-inch plate is shown in Fig. 367. Note the stretch in the outer fibres of the weld metal. The weld was made in V'd plate with the shielded arc. This stretch corresponds to an elongation of 54%.

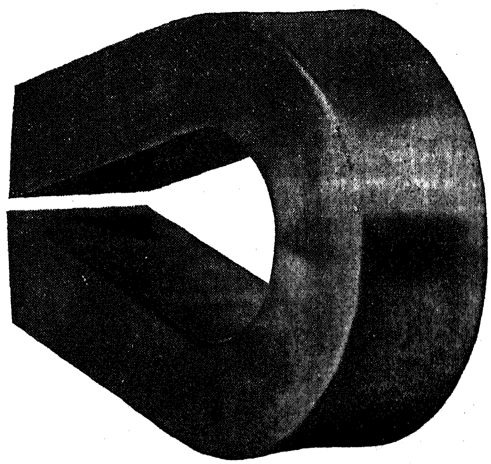


Fig. 367. Free bend test specimen showing stretch in outer fibres of shielded arc weld.

Fillet Weld Break Test—Soundness—Another simple, low-cost test is the fillet weld break test. This requires a minimum of test equipment (a hammer). It is a test for soundness.

Shearing Strength—Transverse and Longitudinal Welds—This test which shows the actual shear strength of a welded joint requires a low-cost specimen and a tensile testing machine of sufficient capacity to break or fracture the joint.

It is frequently used (see Page 275) as a check on work because of its rather low cost, and ease of testing.

Tests other than those specified in the Standards are frequently used, such as the notched bar test, and endurance test.

Notched Bar Test—The notched bar test serves as a guide in the selection of material of low sensitivity to notch effects. The test is made by a continuous application of the load. This must be very definitely and positively differentiated from notch effects where load pulsates or *varies* as in the endurance test, (see Page 280) and no general relation existing between the two has been shown.

The notch bar test indicates the differences or relations of steels which are of different sensitivity to notch effect: Impact tests concern the speed at which the metal is deformed. Due to the method of making the notched bar test, later described, it is referred to as an impact test.

These tests—notched bar and impact—are made by breaking or deforming a bar, by a blow supplied by a pendulum, and the energy required is determined in foot pounds. (See Fig. 369.)

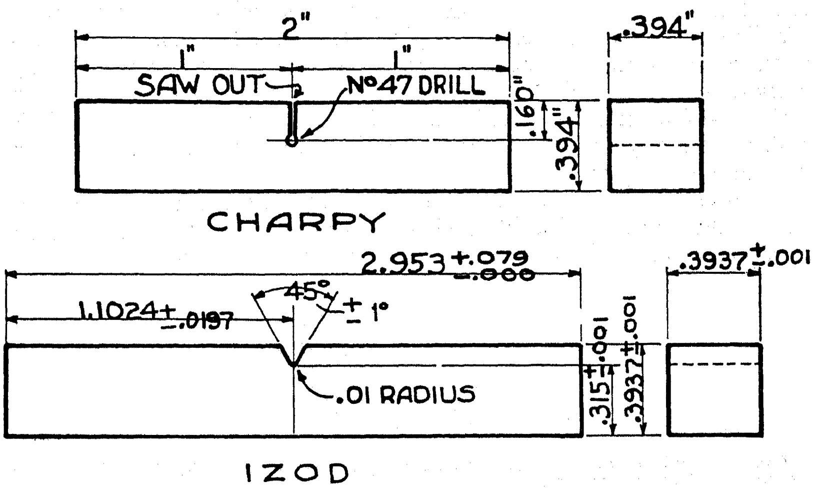


Fig. 368. Diagram of specimen for notch-impact test of weld metal.

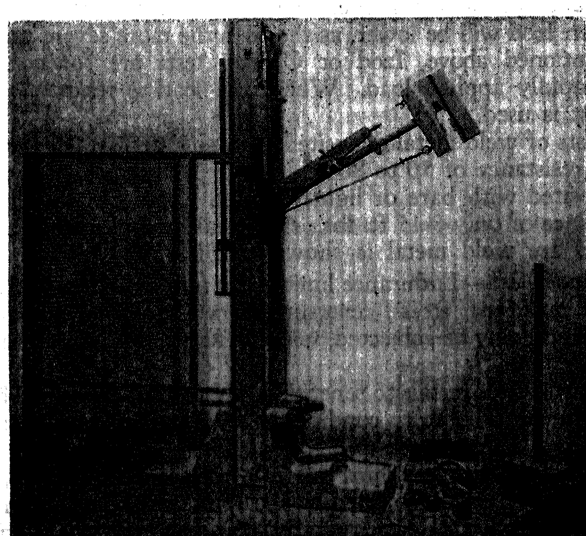


Fig. 369. Universal machine for Izod, Charpy and other impact tests.

Both Charpy and Izod swinging pendulum types are used. The general principles are the same. In the Charpy machine, the test specimen (see Fig. 368) is supported at both ends 1.575 inches between supports placed on a split anvil and broken by a blow opposite the notch.

In the Izod test, the bar is held in a vise, the notch just outside the jaws, and broken by a single blow of the swinging pendulum.

The swinging pendulum is retarded when it strikes the specimen, consequently energy is taken from the pendulum. This energy, usually expressed in foot pounds, is measured by noting the height to which the pendulum rises, which is less than the height from which it started. From this difference and the effective weight of the pendulum, the foot-pounds of energy removed may be calculated. Usually a pointer restrained by friction is so arranged that the motion of the pendulum moves it into position and it indicates directly on a suitable scale the foot pounds. This is similar to any two-pointer gauge with one pointer arranged to stay at maximum reading.

Inspection of the test specimens shows their differences. Test results are not directly related although it is possible to run a series of tests by both methods and obtain a calibration curve for each setup.

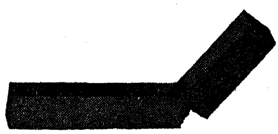


Fig. 370. Typical Izod impact test specimen of shielded arc weld metal showed shock resistance of 74.5 foot pounds.

Izod values are usually higher than Charpy due to the greater cross section except in those cases where steel is exceedingly sensitive to notch effect. Then Izod will be lower, as the V is the more severe notch.

As mentioned above, Izod or Charpy tests are for continuously, although rapidly applied load. Where the load is repeated or varied, another test is used.

Izod tests of weld metal deposited with shielded arc electrodes show an impact resistance of 50 to 80 ft. lbs., or 3-8 times higher than weld metal deposited with bare or lightly coated electrodes which have impact resistance of only 8-15 ft. lbs. A typical Izod impact test specimen of shielded arc weld metal is shown in Fig. 370.

Endurance Test—Endurance limit is given in pounds per square inch. This is the maximum stress, reversing from tension to compression, to which the metal may be subjected, without failure for an unlimited number of cycles.

This resistance of metals to repetition of stress is determined by several tests, made under laboratory conditions. By one method, a suitably prepared specimen is bent back and forth. Another approach is to rotate a beam, suitably loaded. A third test is in rotating a cantilever. By each method, the specimen is subjected to a definite stress and the number of cycles is measured, the cycle usually consisting of a variation from maximum tension to maximum compression—both stresses being imposed

by transverse loading. Hence, in this case, the stress range is equal to twice the maximum tensile or compression stress. The stress range is determined and a record made of the number of cycles imposed before failure.

For usual steels the maximum stress which will permit operation for 10,000,000 cycles or more is taken as the endurance limit. The reason for this is that when tests are made at different unit stresses the number of reversals before failure increases as the stress decreases. A point is reached beyond which any increase in number of reversals does not produce failure. This point is usually at less than 10,000,000 reversals for usual steels.

(Endurance limit for a sound ferrous metal is approximately 45% of its ultimate tensile strength.)

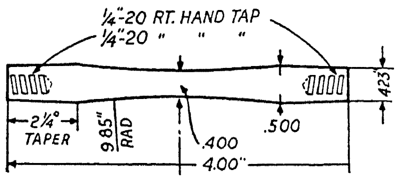


Fig. 371. Specimen for fatigue test of weld metal.

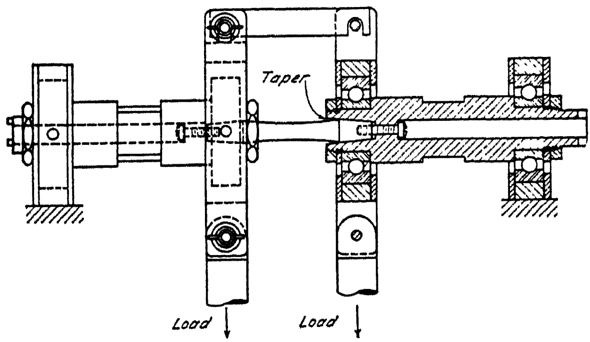


Fig. 372. Attachment to rotating-beam testing machine for fatigue testing.

Fig. 373. Typical fatigue test specimen of shielded arc weld metal after ten million reversals with 30,000 lbs. per sq. in. stress in outside fibres.

A simple endurance test may be made as follows: The test specimen (Fig. 371) is mounted in a machine as shown in Fig. 372. It forms the center of a discontinuous shaft or tube. The entire assembly is mounted in ball bearings at the outer ends of the shaft and is rotated by a small motor. Weights are suspended from the shaft assembly by means of

ball bearings. This permits placing a load on the specimen and rotating the assembly with the load applied. As the assembly rotates, the stress is changed from compression to tension with each revolution of the specimen.

Failure of the specimen breaks the shaft assembly and stops the motor. Number of reversals of stress are read upon a suitable counting indicator.

Radiographic Tests—The soundness of metals may be studied by means of radiographic tests, utilizing either the X-ray or gamma rays. The films obtained by use of X-ray are called exographs, and those by use of gamma rays, gammagraphs. Both are generally termed radiographs. The film (radiograph) is obtained by placing it as close to the weld surface as practicable, if possible not greater than one inch distant from side opposite source of radiation, and exposing it by use of a suitable technique. This technique should be such as to determine quantitatively the size of defects with thickness equal to and greater than 2% of the thickness of the base metal. The radiographs are suitably marked or identified and are studied for indications as to slag inclusions, porosity, cracks, etc. in the metal. Effectiveness of the method has been demonstrated by many thousands of feet of weld which have been radiographed. Structures such as Norris Dam pipe (see Fig. 1062) have been X-rayed in the field. That the quality of shielded arc welding is very high is clearly indicated by these tests.

Resistance to Corrosion—Corrosion is a problem of interest to everyone. The gradual disintegration which occurs in most metals is illustrated by the familiar rusting of steel in air. In contrast, corrosive action may be speeded up until it becomes quite rapid as when some metals are exposed to highly corrosive agents.

The superior corrosion resistance of weld metal produced with shielded arc electrodes is shown by a simple test. Two beads, one made with bare or lightly coated electrodes and the other with shielded arc

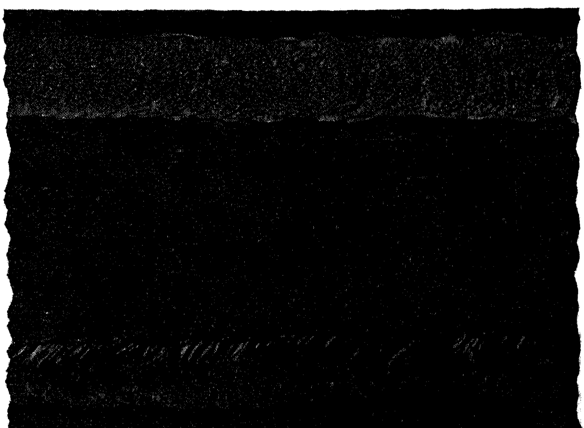


Fig. 374. This specimen shows the effects of boiling in 50% hydrochloric acid on a weld made by bare or washed electrodes in mild steel plate (upper weld), and a weld made in the same plate with the shielded arc (lower weld).

electrodes, are applied side by side on the same plate. The plate is then immersed in mild acid. In a comparatively short time the bead made with the bare electrode will become very porous while the shielded arc deposit will show no corrosion. See Fig. 374.

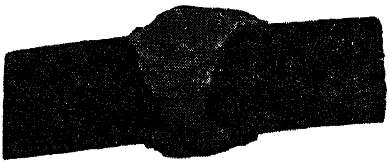


Fig. 375. Cross section of a welded joint made in mild steel with shielded arc electrode showing the relative effects of accelerated corrosion (boiling in 50% hydrochloric acid) on the base metal and the weld metal.

Accelerated laboratory tests are often employed to determine resistance to attack by various reagents. Results are measured generally in terms of loss of weight per square inch of surface exposed or in inches of penetration per month. Under carefully controlled test conditions, accurate comparative data may be thus obtained.

It should be noted, however, that laboratory corrosion tests must be interpreted as having occurred under the exact conditions of the tests and these tests act only as a guide in judging the performance of the joint, in actual field service.

PART V

WELDABILITY OF METALS

Factors Affecting Weldability
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Abrasion Resisting Steels
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Chrome-Molybdenum Steel
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Lead Bearing Steels
High Carbon Steel
Medium High Carbon Steel
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Cast Steel
Malleable Iron
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Forgings
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Bronze
Brass
Aluminum
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PART V

WELDABILITY OF METALS

While most metals can be arc welded with more or less satisfactory results, the economy and degree of satisfaction of welding various metals may be affected by any one of the following factors:

(a) *Oxidation:*

1. Oxidation producing a gaseous oxide of some one of the elements causing gas holes in the weld metal.
2. Oxidation producing solid oxides which have a melting temperature higher than the metal, thus causing slag inclusions.
3. Oxidation producing oxides which are soluble or which are heavier and sink in the molten metal and which render the weld metal brittle or of low strength.

(b) *Vaporization:*

Vaporization of some element in the metal which vaporizes at a temperature lower than the melting point of the metal.

(c) *Non-Metallic Inclusions:*

Some metals may contain finely divided non-metallic inclusions which have a melting point higher than that of the metal and therefore did not coalesce when the metal was refined but do melt and coalesce under the high temperature of the arc and then form visible slag inclusions.

(d) *Change of Structure:*

Change of Structure or arrangement of elements within the metal may take place during arc welding causing change of physical properties or change of resistance to corrosion, etc.

(e) *Gas Solubility of Metal:*

1. Different elements may affect the solubility of various gases at different temperatures and a decrease in solubility of a gas with a decrease in temperature at the freezing point may cause porosity in weld metal.
2. The burning out or elimination of an element during welding may cause the capacity of the metal for a given gas to decrease and thus cause the gas to be given up producing porosity in the weld metal.
3. Absorption of gases during welding which form stable compounds with elements in the metal and thus alter the composition and physical properties of the weld metal.

(f) *High Coefficient of Thermal Expansion* or high contraction of weld metal upon cooling.

(g) "*Hot Shortness*" or low strength of the metal at high temperatures.

(h) *Thermal Conductivity* or rate of transfer of heat from fusion zone.

The above outline indicates why some metals are more satisfactory than others.

A careful study of these factors indicates that most of the possible undesirable characteristics can be corrected by one or more of the following methods:

(a) Selection of metal within the permissible class most suitable for arc welding.
(b) Use of a proper shielded arc.
(c) Use of proper fluxing material.
(d) Use of proper electrode or filler metal.
(e) Proper welding procedure.
(f) In some cases subsequent heat treatment may be required.

In considering the weldability of any metal it should be borne in mind that the weld largely depends upon the characteristics of the weld metal which may come from two sources, viz., base metal and electrode or filler metal.

If little or no electrode or filler metal is used the proper selection of the base metal becomes of prime importance. If the weld metal comes mostly from the electrode or filler metal then the selection of the proper electrode or filler metal becomes of prime importance. However, both electrode and base metal are subjected to similar requirements during arc welding and both should be of best arc welding quality although in many cases the electrode or filler metal serves as a corrective for the base metal.

Why Some Steels Weld Better Than Others

In steels exclusive of alloy steels the carbon content is the common denominator by which different grades of steel are chosen for various commercial uses. The carbon content of the various grades of steel ranges from approximately .04% to 1.65%. All of the steels may be arc welded; however in the case of the higher carbon steels, special technique and electrodes are required (see Page 322). The amount of carbon, however, is not the sole determining factor in the weldability of steel. Many additions, impurities and alloying elements used in steel affect the arc welding characteristics of the steel. Some of these elements are not limited by the usual steel specifications. Thus two lots of steel purchased under the same commercial specifications may have different welding characteristics. Some of the elements found in steel which may affect its gas solvent power and arc welding characteristics are aluminum, silicon, carbon, manganese, titanium, nickel, vanadium, chromium and molybdenum.

For example, steel having a carbon content below .15% has a very high gas absorption power. Thus when such steel is welded considerable quantities of gas in the ambient atmosphere are absorbed by the molten metal. It is therefore essential that the arc welds in such steel be completely shielded during welding. Steel having a silicon content of about .1% or greater may make welding unsatisfactory unless other alloying or deoxidizing elements are present. Also a content of more than .01% of aluminum may cause a poor weld unless the steel also contains a certain proportion of other deoxidizing elements. It should be noted that other elements may and do affect these limits for aluminum and silicon. However, steel having a high aluminum content can be welded satisfactorily

if a corrective autogenizer flux or filler metal is applied during the welding process. In general, however, the presence of nickel or vanadium may improve the weldability of the steel to a small degree.

If the steel contains slag inclusions which have a melting temperature between 1600° and 2500° C., they may melt, coalesce before freezing and form slag pits in the weld. Alumina, Al_2O_3, is a typical example of such slag material and may result from deoxidizing steel with aluminum, or it may come from the furnace or ladle lining.

A fairly common cause of poor welding quality, which is not apparent from analysis of sample taken in the usual way, is segregated layers of sulphur in the form of manganese or iron sulphide. These layers cause gas pockets or other defects at the fusion line when arc welding. These segregated layers can be determined by microscopic examination or more easily by deep etching a cross section or by the "Homogeneity Test" specifications of the American Society for Testing Materials.

Homogeneity Test.—A sample taken from a broken tension specimen shall not show any single seam or cavity more than 1/4" in length in either of the three fractures obtained in test for homogeneity which shall be made as follows:

The specimen shall be nicked with a chisel or grooved on a machine, transversely, about 1/16-in. deep in three places, about 2 in. apart. The first groove shall be made 2 inches from the square end; each succeeding groove shall be made on the opposite side from the preceding one. The specimen shall then be firmly held in a vise with the first groove about 1/4-in. above the jaws; and the projecting end broken off by light blows of a hammer, the bending being away from the groove. The specimen shall be broken at the other two grooves in the same manner. The object of this test is to open and render visible to the eye any seams due to failure to weld up or to interpose foreign matter or any cavities due to gas bubbles in the ingot. One side of each fracture shall be examined and the lengths of the seams and cavities determined, a pocket lens being used if necessary.

In general, if difficulties arise in arc welding, one of the first things to do is check analysis of steel, make radio-graphic tests and make "Homogeneity Tests" as described above.

Analysis of the steel to be welded should be compared with the recommended analyses given hereinbelow.

From the above discussion of the apparent difficulties encountered in welding steel of various analyses, it would appear that where sound, tough welds are desired, only certain grades of steel should be used. This, however, is not entirely true, as it has been found that with proper welding procedure with a completely shielded arc and in some cases with the addition of a corrective autogenizer flux or filler metal applied to the material to be welded, welds of good physical characteristics can be produced in many grades of steel, that would give unsatisfactory results without these controlling measures.

It should be clearly understood that all commercial grades of steel are readily weldable except spring steel and tool steel which have high carbon content. However, welds in some steels may have better physical characteristics than welds in other steels. When the physical characteristics are not up to requirements, it must not be immediately inferred

that some one particular item is the cause. The following conditions should be considered and checked. The welding generator must be properly adjusted and connected to the work. The electrode must be properly used, that is, the procedure for welding the work at hand must be correct and the steel must be readily and easily weldable. Tests for chemical content can involve only a very small percentage of the total steel used for a given job, consequently the chemical content in some part of the steel may not be the same as in some other part. The reader is referred to previous remarks regarding sulphur.

In testing steel for use as electrode weld metal, the percentage of the total material is very much larger than in the case of steel as base metal. Due to the electrode's small size, the metal as tested tends to be very uniform. It follows that the weldability of the steel must be considered as a very important factor. It must not be inferred that only one factor can be responsible in case a welded joint does not meet requirements as to physical properties.

Specifications for Steels of Good Weldability

The importance of using steel of good welding quality increases in proportion to the amount of base metal entering into the weld. Steels conforming with the following specifications will be of best welding quality in the respective classes. While some steel not conforming with the following specifications may be of good arc welding quality, it is believed that steel conscientiously made within these specifications will have good quality for arc welding.

In cases where the steel will be required to withstand considerable drawing, forming or have special finish or have special physical properties, some modifications of these specifications may be necessary and the steel manufacturer should be consulted.

The general purpose steel, the analysis of which immediately follows, is the best for arc welding at high speeds and should be used in all cases where physical requirements permit.

ANALYSIS OF GENERAL PURPOSE STEEL

	Per Cent Recommended	Per Cent Limits
Carbon	.17	.15 to .25
Manganese	.45	.35 to .60
Silicon	.05	.07 max.
Sulphur	low	.05 max.
Phosphorus	low	.045 max.

Aluminum..........not over 2 oz. per ton added to steel unless it has been semi-killed with silicon†, in which case the aluminum addition should be as low as practical. For this classification steel can be considered semi-killed with silicon if the silicon content is between .04% and .07%.

†If silicon is added prior to the aluminum addition in the proper ratio, the non-metallic inclusions coming out of the steel during welding will have sufficiently low melting point to be self-fluxing and will not form slag pockets along the edge of the welds. The addition of aluminum or of vanadium seems to have a beneficial effect in reducing the tendency toward porosity of welds in silicon-killed steels.

The maximum welding speed for soft steel, which permits considerable cold forming, will generally be less than that for the higher carbon general purpose steel.

ANALYSIS OF STEEL FOR CONSIDERABLE COLD FORMING

(Most warehouse stock sheets 8 gauge and thinner will generally be between .06% and .15% C.)

	Per Cent Recommended	Per Cent Limits
Carbon	(as high as practical)	.06 to .15
Manganese	.40	.35 to .55
Silicon	....	.07 max.
Sulphur	low	.05 max.
Phosphorus	low	.045 max.

Aluminum..........not over 2 oz. per ton added to steel unless steel has been semi-killed with silicon†, in which case the aluminum addition should be as low as practical. For this classification steel will be considered semi-killed with silicon if silicon content is between .035% and .07%.

ANALYSIS OF .30 CARBON STEEL

	Per Cent Recommended	Per Cent Limits
Carbon	.30*	.25 to .35*
Manganese	.60	.50 to .90
Silicon	.06	.09 max.
Phosphorus	low	.045 max.
Sulphur	low	.055 max.

Aluminum..........not over 2 oz. per ton unless the steel has been semi-killed with silicon†, in which case the aluminum should be as low as practical. For this classification steel will be considered semi-killed with silicon if the silicon content is between .04% and .09%.

ANALYSIS OF .40 CARBON STEEL

	Per Cent Recommended	Per Cent Limits
Carbon	.40*	.35 to .45*
Manganese	.80	.60 to .90
Silicon	.07	.10 max.
Phosphorus	low	.045 max.
Sulphur	low	.055 max.

Aluminum..........not over 2 oz. per ton added to steel unless steel has been semi-killed with silicon†, in which case the aluminum addition should be as low as practical. For this classification steel will be considered semi-killed with silicon if the silicon content is between .04% and .10%.

†If silicon is added prior to the aluminum addition in the proper ratio, the non-metallic inclusions coming out of the steel during welding will have sufficiently low melting point to be self-fluxing and will not form slag pockets along the edge of the welds. The addition of aluminum or of vanadium seems to have a beneficial effect in reducing the tendency toward porosity of welds in silicon-killed steels.

*In view of the fact that carbon is the most potent hardening element, lower carbon steel should be used for welding if other requirements permit. If steel is higher than .35% carbon and optimum physical properties are required, it should be normalized, i.e., reheated slightly above its upper critical point and cooled in still air after welding and subsequently heat treated as required.

Rimmed Steel.—An incompletely deoxidized steel normally containing less than .25% carbon and having the following characteristics:

(a) During solidification an evolution of gas occurs sufficient to maintain a liquid ingot top, ("open" steel) until a side and bottom rim of substantial thickness has formed. If the rimming action is intentionally stopped shortly after the mold is filled the product is termed "capped steel."

(b) After complete solidification, the ingot consists of two distinct zones: A rim somewhat purer than when poured and a core containing scattered blowholes with a minimum amount of pipe and having an average metalloid content somewhat higher than when poured and markedly higher in the upper portion of the ingot.

Killed Steel.—A steel sufficiently deoxidized to prevent gas evolution during solidification. The top surface of the ingot freezes immediately and subsequent shrinkage produces a central pipe.

A semikilled steel, having been less completely deoxidized, develops sufficient gas evolution internally in freezing to replace the pipe by a substantially equivalent volume of rather deep-seated blow-holes.

The .40% carbon steel should be heat treated after welding if best results are to be obtained.

Proper procedures and speeds for welding the general purpose steel previously mentioned are given in Part III.

High Tensile Low Alloy Steels

With ductility and ease of forming similar to ordinary structural steel and a higher yield point obtained without the requirement of heat treatment, the low-alloy high-tensile weldable steels serve a most useful purpose. The effectiveness of the use of this high tensile steel is illustrated in the Machine Design section (Pages 379 to 517). Here, it should be borne in mind that the modulus of elasticity of these high tensile steels is the same as that of structural steel and that suitable provision must be made in the design so that the proper sections, i. e., distribution of metal, may be obtained to take advantage of the high tensile strength.

If in a design, deflection is the governing factor (see Page 389, Machine Design), then for a given shape of cross section and load this deflection will be the same for any type of steel. However, if the design permits a change or modification of the cross section and high tensile steel is used, then the maximum unit stress may be increased. This modified cross section will be less in area, resulting in a weight reduction and a lower cost. The higher unit stresses available are governed by the conditions of loading, the elastic limit, the effect of welding and forming on the steel and other physical properties such as resistance to fatigue and impact. From consideration of the characteristics of high tensile steel, such as its high yield point, it is obvious that a structure built of such steel may be sufficiently strong while having a deflection somewhat greater than that usually allowed. The exact amount of deflection will, of course, be dictated by the design.

The use of high tensile steels generally results in thinner sections because of the high physical properties and resistance to corrosion. Corrosion resistance prevents the material from becoming thinned and weakened by corrosive action to the point where unit stresses are increased above the maximum allowable value. The use of thinner sections makes it necessary to consider such factors as the possibility of buckling under load or, in some instances, the drum effect produced by a large thin sheet of metal.

High tensile steels are made in a number of different alloys by various steel manufacturers. Analysis and properties of these steels are given in the following table, the data having been taken from published literature.

Name of Steel	ANALYSIS OF STEEL IN PER CENT							PHYSICAL PROPERTIES		
	Carbon	Chromium	Manganese	Silicon	Phos-phorus	Copper	Others	Yield Point Lbs./Sq.In.	Tensile Strength Lbs./Sq.In.	Percent Elongation in 2"
Corten	.10	.50–1.50	.10– .30	.50–1.00	.05	.30– .50		50,000–60,000	65,000–75,000	22–27
Cromansil	.15	.50	1.25	.75				60,000	95,000	24
Manten	.35		1.25–1.70	.15 min.	.05	.20 min.		55,000–65,000	80,000–90,000	20–25
R.D.S.	.08–.23		.70– .75			1.30–1.40	.11–.16 MO. .75 Ni.	65,000–70,000	74,000–90,000	20–50
Silten	.40		.70– .90	.20– .30	.05			45,000	80,000–90,000	18–23
Yoloy	.08–.20		.40– .65			1.00	2.00 Ni	58,000–73,000	74,000–92,000	29–34
Mayari R	.08–.20	.20–1.00	.50–1.00	.05– .50	.04–.12	.50– .70	.25–.75 Ni.	50,000–60,000	70,000–80,000	20–30 in 8 in.
HS–1	.14		.70– .90	.15– .20		.30 max.		70,000	80,000	19 in 8 in.
Carbon Moly	.10–.30		.30– .60	.10– .20			.20–.60 MO.	45,000–50,000	60,000–80,000	22–25
Jalten	.35		1.25–1.75	.30 max.		.40		50,000	80,000	20
HS–2	.20–.30	.12	1.20–1.60	.15– .20		.30		85,000	105,000	12
Hi–Steel	.12		.50– .70	.30	.10–.15	.90–1.25	.45–.65 Ni.	55,000–65,000	78,000	22
HT–50	.12		.15– .90		.05–.15	.30– .80	.25 MO. .30–.80 Ni.	47,000	67,000	28
Centralloy .08C .30C	.08–.30	.25	.60– .90	.50		.40– .60	.25 Ni.	50,000–60,000 60,000–72,000	65,000–75,000 75,000–90,000	25 20
70–90	.25	.25	.75	.25	.08–.10	.30– .50	.25 Ni.	70,000	90,000	20
Otiscoloy	.12	.10	1.35	.08	.15	.50	.10 Ni.	50,000	70,000	30

As indicated in the table on Page 293 high physical properties are obtained in the steels having rather low carbon content. This low carbon aids weldability.

As indicated in the discussion of high carbon steel (Page 322), properties such as higher ultimate tensile strength may be obtained by the use of carbon content with heat treatment. Also, heat treatment may be exceedingly expensive, difficult to apply, and in some cases not effective throughout the section.

By the use of certain alloying elements, the yield strength and tensile strength are increased without a reduction of ductility. Reference to the above table will show the effect of these alloying elements on physical properties. The alloying elements should be relatively low in cost and in general the carbon should be kept relatively low for good weldability. With relatively low carbon (as compared to the carbon usually used to obtain high ultimate strengths) and manganese ranging from .40% to as high as 1.75%, the elongation in 2″ may be about 30% and in some cases even higher. It should be noted that the increased strength is due to the manganese rather than silicon.

For steels which might be termed "manganese base" (manganese 1% or more,) having hardening qualities, the carbon content should be kept low for good weldability. Carbon of the order of 12 to 15 points is advisable.

As the use of these high tensile steels increased it was evident that to obtain the maximum efficiency it would be necessary to have some corrosion resisting properties so that the design as laid out initially would require no greater thickness because of ultimate corrosion than the load or service requirement demanded.

Weldability of course, is also very necessary. Copper was used for this purpose up to about 20 to 25 points.

Copper has long been used in copper-bearing steel of low-carbon content for corrosion resistance. When copper is added in larger percentages than those customary in the "copper-bearing" steel, the effect is to improve the physical properties, particularly the ratio of the yield point of the metal to the metal's ultimate strength. This effect can be noted in the high tensile steels. In one case adding 1% copper increases the yield point as much as 50%.

The same comments regarding limitation of carbon apply to the weldability of nickel steel or nickel-copper steel.

The design problem for low-alloy high-tensile steel does not require any special consideration except that it should be kept in mind that for maximum efficiency, sections should be laid out so that maximum rigidity is obtained. In other words, get the best distribution of the metal, which will permit use of high unit stresses.

The high tensile steels can be welded readily with the proper type of shielded arc electrode, designed especially for welding such metals. This electrode and correct procedure — generally the same as for welding plain carbon steels — will provide welded joints of similar physical characteristics to those of the metal welded. Yield points of 50,000 lbs. per sq. in. as compared to 32,000 lbs. per sq. in. for low carbon steel, permit considerable weight reductions, in some cases as much as 30% to

50% over previous designs of low carbon steel. The chemical composition of these various steels indicates a wide variation in the alloying elements and their relative proportions. Commercial, and perhaps patent situations may have something to do with this. Nevertheless, high yield, high ductility, high impact and endurance values, ease of forming, good corrosion resistance and good weldability are obtainable in these various steels.

At first thought, it might seem desirable to have a coated electrode of composition similar to each of these alloys for their welding. However this is unnecessary and in some cases undesirable for frequently, alloyed electrodes in going through the arc have their analyses and characteristics changed.

Excellent joints of the same high physical as the base metals may be obtained provided a suitable high quality electrode, designed for use with low-alloy high-tensile steels, is used. The high quality results obtainable are indicated by Fig. 376 which illustrates a free-bend test. This unusual test showed a ductility of 86% elongation in outer fibres of the weld. The reader's attention is called particularly to the plastic flow of the metal on the inner side of the bend.

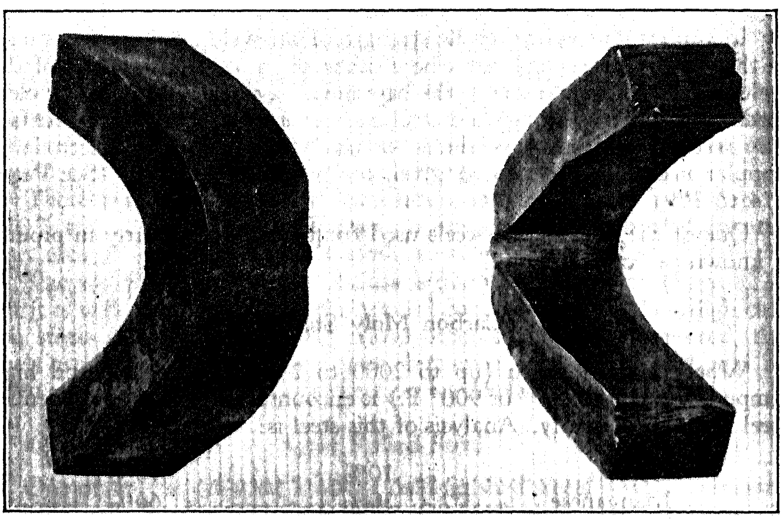


Fig. 376. Free bend test of shielded arc weld in high tensile steel which showed ductility of 86% elongation in outer fibres. Note plastic flow of metal on inside of bend.

The high quality welds available in high tensile steels, and the inherent high physical properties in the steels themselves, make it possible to obtain superior service life at very moderate cost.

For details on welding procedure, see Page 190.

In welding high tensile steels, welding current of positive polarity is used, that is, electrode positive and work negative. *When welding in a*

flat position the arc voltage ranges between 24 and 28 volts and, in some cases, above 30 volts. In general, currents approximately in the middle of the range given in the following tabulation should be used:

1/8″ electrode	75 to 130 amperes
5/32″ electrode	90 to 175 amperes
3/16″ electrode	140 to 225 amperes
1/4″ electrode	180 to 325 amperes
5/16″ electrode	250 to 400 amperes

When welding in vertical or overhead position 5/32″ size electrode is generally used for most work. However, the 3/16″ size electrode is used for finish beads on heavy plate. In *vertical* welding, welding should start at the bottom of the joint, building up a shelf of weld metal and weaving the electrode from side to side for the full width of the joint. Vertical welding is covered in detail on Page 144. In *overhead* welding the weld should be made with several narrow beads. Each bead should be entirely cleaned before applying the next bead. Recommended current for vertical or overhead welding is as follows:

1/8″ electrode	75 to 130 amperes
5/32″ electrode	100 to 160 amperes
3/16″ electrode	125 to 180 amperes

In applications where tensile strength of the weld need not be as high as that of the base metal but where other physical characteristics of the weld should be comparable to the base metal, a shielded arc type of electrode as used for welding mild steel can be employed with very satisfactory results. Welding procedures for use with this type of electrode of popular make are the same as given for welding mild steel. (See Pages 154 to 179).

One of the high tensile steels used frequently, particularly in piping, is known as "carbon moly."

Carbon Moly Steels

Where high pressure (up to 2000 to 2500 lbs./sq. in.) and high temperature (up to 800° or 900° F.) is encountered, carbon molybdenum steel is used frequently. Analysis of this steel is:

Carbon	.10%	.50%
Manganese	.30%	.60%
Silicon	.10%	.20%
Molybdenum	.20%	.60%
Phosphorus	.04% max.	
Sulphur	.05%	

Physical properties are:

Ultimate tensile strength — 75,000 lbs./sq. in.
Yield point — 45,000 — 50,000 lbs./sq. in.
Ductility — 22% — 26% elongation in 2″.
(These may vary slightly depending upon exact analysis.)

When stress relieved, the ultimate tensile strength is 65,000 — 70,000 lbs./sq. in., yield point is 50,000 — 60,000 lbs./sq. in., and ductility is 26% — 28% elongation in 2″.

When carbon content is low (approximately .15%), these steels are readily weldable. In pressure vessels, this low carbon content may be used, but in piping carbon of the order of .30% should be present. In this case, preheating is generally required. The preheat temperature is usually from 400° to 650° F., its purpose being to reduce the rate of cooling (see high carbon steel — Page 322).

Welding procedure is essentially the same as for mild steel. In the case of piping, a back up ring is recommended generally to keep the inside of the pipe clean. The ring, not inset in the pipe, causes only slight obstruction which is not objectionable, in most cases.

Stress relieving is generally specified when the thickness of the metal is greater than ⅜″. Temperature of 1200° — 1250° F. is used with usual procedure as to time of heating (one hour per inch of thickness) and length of pipe heated (6 times thickness on each side of weld).

The cooling rate is from 200° — 250° F. per hour down to 150° — 200° F. in which case cooling may be done in still air. Stress relieving may be done electrically. See Page 102 discussing use A. C. motor generator sets for this purpose.

Abrasion Resisting Steels

Steels of relatively high carbon content (above .15% to .20%) have a corresponding greater hardenability and consequently are abrasion-resisting to a considerable degree. This is due to high carbon content, and should not be credited to the other alloying elements.

There are also steels with low carbon and some manganese (up to 1.00% to 1.25%), copper and chromium which have 30% to 50% greater resistance to abrasion than mild steel.

The welding of steels of this class is discussed elsewhere (Page 322) but it is well to keep in mind the general conditions of welding high carbon steels (Page 320). Where alloys other than carbon are used, the steels are weldable to a high degree, but even here attention should be given the alloys used and their effect on hardenability.

Cold Rolled Steel

One of several different kinds of cold finished steels is what is known as "cold rolled"; the term designating the method of reducing the cross section of bars or shafting. A good surface is obtained by various processes, prior to the mechanical treatment. The result is a product with bright, smooth finish, accurate as to size, with an increase in tensile strength and yield point, and readily machinable. It is therefore used where accurate, smooth surfaces are desired, such as for jigs and fixtures. The readily machinable characteristic is frequently obtained by use of sulphur, which produces a free cutting steel — but this sulphur is the cause of porosity when welded. However, cold rolled of weldable quality may be obtained when specified. Proper content of carbon (see Page 290) is necessary.

When sulphur is high (see Page 290) then it is advisable to use a procedure and electrode which will result in minimum penetration, but adequate fusion so as to result in minimum amount of base metal being washed into the bead, thereby reducing porosity.

Chrome-Molybdenum Steel

The analysis of chrome-molybdenum steel is approximately as follows:

Carbon	.25% to .35%
Manganese	.40% to .60%
Phosphorus	.040% max.
Sulphur	.045% max.
Chromium	.80% to 1.10%
Molybdenum	.15% to .25%

ASTM Spec. 182-36 Grade F7 applications for use at temperatures between 750° and 1100° F. for pipe flanges, valves, fittings, etc.

Specifications for the strength of chrome-molybdenum steel vary. United States Army requires a minimum tensile strength of 125,000 lbs. per sq. in. after heat treatment. Chrome-molybdenum steel, unheat-treated, has a tensile strength in the neighborhood of 80,000 lbs. per sq. in. However, after proper heat treatment its tensile strength will range from 125,000 to 160,000 lbs. per sq. in. Likewise tensile strength of welds made in chrome-molybdenum steel approximately doubles on heat treatment.

With the shielded arc process using a metallic electrode having a heavy extruded coating welds may be produced in chrome-molybdenum steel having a tensile strength of 125,000 to 150,000 lbs. per sq. in. after heat treatment. Before proper heat treatment such welds will develop a tensile strength of 60,000 to 80,000 lbs. per sq. in.

Using a carbon arc with a piece of the base metal as filler material, welds can be produced in chrome-molybdenum steel having a tensile strength of 60,000 to 70,000 lbs. per sq. in. before heat treatment. After proper heat treatment welds so produced will show a tensile strength of 125,000 to 160,000 lbs. per sq. in. One of the reasons for the higher tensile strength of weld metal in chrome-molybdenum steel is due to the mixture of base metal with deposited metal in the weld. Although the manual carbon arc with filler material of chrome-molybdenum steel will give the best results, this method of welding is not as fast or as easy to handle as the shielded arc process with metallic electrodes.

For welding chrome-molybdenum steel the shielded arc process using a shielded arc electrode is most satisfactory.

Procedure for an electrode especially developed for SAE 4130 and X 4130 steels (analysis given above) is as follows: Polarity: Electrode negative, work positive.

Size Electrode	Amperage	Arc Voltage
1/8"	65 – 120	23 – 26
5/32"	80 – 160	23 – 26

Heat treatment to be used after welding with electric arc is approximately as follows:

1. Normalize to 1650°–1750° F. and cool slowly in furnace below red heat.
2. Heat to 1550°–1655° F. and quench in light oil.
3. Draw 950° F. or other temperature to secure desired hardness.

Chrome-Nickel ("Stainless") Steels

What is known to the layman as "Stainless Steel" is the most widely used of the chrome-nickel-iron group. Strictly speaking, stainless steel is an alloy of iron, chromium and carbon. The amount of carbon is such that the alloy hardens upon quenching. This alloy is suitable for cutlery, surgical instruments and applications where high physical properties, hardness and wear resistance are required. It does not lend itself to deep drawing, forming or welding. Preceded by a careful heat treatment, this requires careful polishing to develop its corrosion resisting properties.

"Stainless Steel" is a term popularly used to designate all stainless alloys. There is a distinction between stainless steel and stainless iron.

Stainless iron, when called stainless steel, is generally an alloy of chromium, nickel and iron, with very low carbon. In this group, known as 18-8 group are Allegheny Metal, Enduro KA 2, Rezistal KA 2, Uniloy, Duralloy 18-8, Sterling Nirosta, U. S. S. 18-8, Bethadur No. 2, Nevastain, Colonial Stainless, Undivall 2VA and many others.

In the 25-12 group are: Republic Steel Corp.'s Enduro HCN, Universal Steel Co.'s Uniloy Special 2411, U. S. Steel Corp.'s U. S. S. 2512, Crucible Steel Co.'s Rezistal 3, Jessop Steel Co.'s Heat Resisting No. 5, Allegheny Steel Co.'s Allegheny No. 44, Latrobe Electric Steel Co.'s Lesco 21-12, Midvale Co.'s Midvaloy 25-10, General Alloys Co.'s Q Alloy Chrome CN1, Sivyer Steel Casting Co.'s Sivyer 62, Cooper Alloy Foundry Co.'s Sweetalloy 22, Michiana Products Corp.'s 100 Alloy, Duralloy Co.'s Duralloy N, Empire Steel Casting Co.'s Empire 24-12, Calorizing Co.'s Calite B-28.

There are a host of different types put out by various companies under different trade names. Most of these have been classified and given standard type numbers by the Iron and Steel Institute. These standard type numbers and analyses applicable thereto, are reproduced in the following table.

In looking over the analyses in the table, it will be noted that in general they can be divided into two classes.

1. Chrome Nickel Alloys (Austenitic)
2. Straight Chrome Alloys (Ferritic)

The Chrome Nickel types containing approximately 17% or more chromium with 7% or more nickel are soft and tough as welded, harden quite rapidly when cold worked, are non-magnetic and cannot be hardened by any form of heat treatment; in fact, quenching from 2000° F. merely softens them and this treatment is used to put these steels in the best condition to resist corrosion.

STAINLESS STEEL TYPE NUMBERS AND ANALYSES

Issued by the American Iron and Steel Institute, New York.

Type No.	Carbon	Chromium	Nickel	Other Elements
301X	.10–.20	16.00–17.50	7.00– 8.50	
*302	Over .08–.20	17.50–19.00	8.00– 9.00	
302B	Over .08–.20	17.50–19.00	8.00– 9.00	Si 2.00–3.00
*303	.20 Max.	17.50–19.00	8.00– 9.00	S or Se .07 Min or Mo .60 Max
x304	.08 Max.	17.50–19.00	8.00– 9.00	
*305	Over .08–.20	18.00–20.00	9.00–10.00	
x306	.08 Max.	18.00–20.00	9.00–10.00	
*307	Over .08–.20	20.00–22.00	10.00–12.00	
x308	.08 Max.	20.00–22.00	10.00–12.00	
309	.20 Max.	22.00–26.00	12.00–14.00	
310	.25 Max.	24.00–26.00	19.00–21.00	
311	.25 Max.	19.00–21.00	24.00–26.00	
312	.25 Max.	27.00–31.00	8.00–10.00	
315	.15 Max.	17.00–19.00	7.00– 9.50	Cu 1.00–1.50 Mo 1.00–1.50
x316	.10 Max.	16.00–18.00	14.00 Max.	Mo 2.00–3.00
317	.10 Max.	18.00–20.00	14.00 Max.	Mo 3.00–4.00
321	.10 Max.	17.00–20.00	7.00–10.00	Ti Min 4 x C
325	.25 Max.	7.00–10.00	19.00–23 00	Cu 1.00–1.50
327	.25 Max.	25.00–30.00	3.00– 5.00	
329	.10 Max.	25.00–30.00	3.00– 5.00	Mo 1.00–1.50
330	.25 Max.	14.00–16.00	33.00–36.00	
343	Over .25	12.00–16.00	12.00–16.00	W 3.00
347	.10 Max.	17.00–20.00	8.00–12.00	Cb 10 x C
403	.12 Max.	11.50–13.00		Turbine Quality
405	.08 Max.	11.50–13.50		Al .10–.20
406	.12 Max.	12.00–14.00		Al 4.00–4.50
410	.12 Max.	10.00–13.50		
414	.12 Max.	10.00–13.50	2.00 Max.	
416	.12 Max.	12.00–14.00		S or Se .07 Min or Mo .60 Max
418	.12 Max.	12.00–14.00		W 2.50–3.50
420	Over .12	12.00–14.00		
420F	Over .12	12.00–14.00		S or Se .07 Min or Mo .60 Max
430	.12 Max.	14.00–18.00		
430F	.12 Max.	14.00–18.00		S or Se .07 Min or Mo .60 Max
431	.15 Max.	14.00–18.00	2.00 Max.	
434A	.12 Max.	14.00–18.00		Si 1.00 Cu 1.00
438	.12 Max.	16.00–18.00		W 2.50–3.50
439	.50–.65	8.00		W 8.00
440	Over .12	14.00–18.00		
441	Over .15	14.00–18.00	2.00 Max.	
442	.35 Max.	18.00–23.00		
446	.35 Max.	23.00–30.00		
501	Over .10	4.00– 6.00		
502	.10 Max.	4.00– 6.00		

*No specified composition limits within the above ranges may be placed on these Types, except carbon may be specified to a four point range within the above limits.

Where definite carbon content .11 or under is specified for Types 302, 305 and 307, the price of Types 304, 306 and 308 respectively apply.

xIn these types manufacturers may accept specifications and furnish material with a guaranteed carbon content of .08 maximum.

The straight chrome types, containing 12% or more chromium with no nickel, are brittle as welded, do not respond to annealing, do not harden much with cold working and are magnetic.

There are, of course, a variety of analyses under each of these classes, but a computation of the tonnages shows that the most commonly and most widely used is the so-called 18-8 variety—that is, having approximately 18% chromium and 8% nickel. (Type Nos. 302, 302-B, 303, 304, 305 & 306.)

Some of the more important properties of annealed 18-8 are listed below, taken from published sources:

Tensile Strength	85,000-95,000 lbs./sq. in.
Yield Point	30,000-40,000 lbs./sq. in.
Elongation in 2"	55-60%
Reduction of area	60-70%
Hardness	135-180 Brinell—77-90 Rockwell B.
Izod Impact	80-120 ft. lbs.
Endurance Limit	Fatigue value is usually 40% to 45% of ultimate strength. Ultimate given is for annealed metal. Work hardening will increase ultimate.
Specific Gravity	7.86 Grams / cu. cm.
Specific Heat	.12 Cal / °C / gm.
Thermal Conductivity	.33 of Low Carbon Steel
Electrical Resistance	6.4 times that of Low Carbon Steel
Thermal Expansion	1.45 times that of Low Carbon Steel
Modulus of Elasticity	28,000,000-30,000,000
Melting Point	2560° F.
Approx. Scaling Temperature	1650° F. (Average, in Air)

Perhaps the most important property of 18-8 is its resistance to corrosion. There has been no single metal found in nature, not even excepting gold and platinum, which is unaffected by corrosive attack in all environments, and no alloy has been developed which remains unattacked in all solutions. The Stainless Iron types of alloys are clearly the cheapest alloys which offer ample resistance to attack under some of the commonest and most active conditions. The industrial reagents which are incapable of attacking clean surfaces of low carbon fully annealed 18-8 under laboratory conditions would make up a very long list, and no attempt will be made here to tabulate all of them. Some idea of the many applications for 18-8 stainless steel may be gained from the following examples of reagents to which such steels are resistant. Acetic acid, cold, at any concentration; acetic acid, hot, up to approximately 10%; alkaline solutions in general, including ammonium hydroxide; bichloride of mercury, dilute (usual antiseptic strength); carbolic acid; carbonated water, citric acid, cold, moderate strength; copper sulphate; fruit and vegetable juices; hydrogen peroxide, hydrogen sulphide; laundry solutions with a few exceptions; milk and dairy products; nitric acid; photographic solutions; salt solution; sea water; sulphuric acid, cold (very slight action); sulphurous acid; wood pulp; yeast; zinc chloride, cold; zinc sulphate.

It should also be mentioned that at ordinary natural temperatures, the atmosphere, with its usual traces of corrosive gases and variable moisture, leaves no evidence of attack upon the surface of 18-8.

Care must be taken in the application of stainless steels. It is quite true that the 18-8 stainless material will withstand certain solutions under laboratory conditions, but when these conditions are encountered in service the laboratory results are frequently found to be misleading. This condition arises because of small traces of various other substances found in the practical applications, and although these substances are present in traces they nevertheless cause the behavior of the solution with the metal to be entirely different, frequently resulting in failures.

As will be noted in the table of analyses, there are various modifications of the 18-8 alloy, each of which has certain advantages under certain conditions of service over the regular 18-8. For example, Type No. 303 contains a relatively high percentage of Sulphur or Selenium which gives the alloy free machining properties. Type 302-B, containing 2.00-3.00% Silicon, is used for resistance to scaling up to 1700° F. Type 316, containing 2.00-4.00% molybdenum has a higher creep strength than regular 18-8 and is more resistant to corrosion by hot sulphite liquors and bleaches encountered in the paper pulp industry. Others, such as 305, 306, 307 and 308 contain slightly higher percentages of chromium and nickel, preferred in some cases for special applications.

As has been previously mentioned, the regular 18-8 alloy, in order to resist corrosion to its fullest extent, must be in its annealed condition, in which the carbon is present in solid solution. Unfortunately, this alloy is unstable under certain forms of heat treatment, namely, when heated in the range between 800° F. and 1400° F.; they undergo a structural change which is detrimental to their corrosion resistant properties, although in some cases their mechanical properties may not be affected to an appreciable extent. The cause of this defect is thought to be due to the preciptation at the grain boundaries of very fine films of chromium-rich carbides, containing as much as 90% chromium taken from the layer of metal immediately adjacent the grain boundary. Under these conditions the chromium content of the metal adjacent the grain boundaries may be so reduced that its resistance to corrosion will be seriously impaired. This phenomenon is generally spoken of as carbide precipitation and the type of corrosion which is then very likely to occur is commonly known as intergranular corrosion. The conditions necessary to produce this change are easily realized during welding, that is heating between 800° F. and 1400° F.

Various methods of reducing or preventing intergranular corrosion have been devised. Heating the welded article to 1850°-2100° F. and rapidly cooling by quenching causes a solution of the precipitated carbides thus eliminating their presence. They will, however, be precipitated again by reheating to 800° to 1400° F., but this treatment may cause distortion of finished parts and in the case of large welded structures may be impossible.

An obvious remedy is to reduce the carbon content of the alloy to such a low value that no carbide could be precipitated. It has been found that 18-8 with a carbon content of .02% is free from susceptibility to intergranular corrosion. However, the cost of production of such an alloy is very high and it is not commercially available. 18-8 with .08% carbon

maximum is usually specified for welded structures and electrode which contains .05 to .07% carbon is used in order to minimize carbide precipitation.

A more recent development of a method of preventing impoverishment of chromium is the addition of an alloying element which has a greater affinity for carbon than has chromium. Types Nos. 320, 321 are such alloys, Titanium being the stabilizing element. Such alloys are widely used for welded members. Though susceptibility to intergranular corrosion in areas adjacent the weld can be effectively prevented by the use of these types, addition of Titanium to welding electrodes has not been entirely successful as most of it is lost during welding. Types 345 and 346 have Columbium as a stabilizing element. Since Columbium is equally as effective and is not lost in the welding operation, freedom from intergranular corrosion in the weld metal is now possible by the use of an electrode which contains this element in suitable proportions.

Another group or alloy is that coming to be known as 25-12 to distinguish it from 18-8. The same general remarks are applicable. This is used for heat resistance up to very high temperatures, such as might be in a chemical plant, heaters, refinery equipment. It resists scaling to a greater degree than 18-8.

Alloys other than 18-8 and 25-12 are coming into more extensive use. One of these is Type 316,18-8MO. This type has greater resistance to certain types of corrosion than the regular 18-8. The addition of Molybdenum has been particularly advantageous where the corrosive agent tends to be of a reducing nature. This alloy has increased resistance to sulphuric, sulphurous, hydrochloric, acetic, phosphoric, formic, citric, tartaric, etc. acids and has been quite successful in handling such acids as sulphite pulp liquor in paper and pulp mill equipment, also bleaching solutions and coal or oil smoke.

Physical characteristics of this alloy are similar to the 18-8 type but the creep strength is improved, thus making its use in high temperature applications advantageous. No heat treatment is usually required after welding. Molybdenum is said to act as a partial stabilizing agent in reducing the carbide precipitate. It is not, however, a complete stabilizer, but does assist in reducing the effect of corrosive attacks.

There are too many additional alloys to discuss in this book, however, the so-called 25-20 or Type 310 is used quite extensively. This is used where high strength and greatest oxidation resistance is wanted at highest temperatures.

An electrode of this type (310) is now being used to weld alloyed steels of the so-called armor plate type.

The welding of these alloys presents similar problems in general and their welding will be discussed as a group.

General Procedure—The general procedure for mild steel welding should be followed, taking into account the stainless steel characteristics which differ from those of mild steel. They are higher electrical resistance, lower thermal conductivity and higher thermal expansion (about 50% greater than mild steel).

In welding the stainless steels, it is important to prepare and fit the work carefully. The edges should be clean of all foreign material. Especially in light gauges, the work should be clamped and held in alignment during welding to reduce any tendency to buckle.

Direct current is recommended with the electrode positive and the work negative. The recommended current will be slightly less than for mild steel. The arc length should be as short as possible without sticking.

Electrodes 1/4" or larger should be used with caution to avoid undue loss of the chromium. Excessive weaving in any size should be avoided. In general a weld made with a number of straight beads is recommended. Care must be taken to clean thoroughly all slag from each bead before another is applied.

Since the electrical resistance of stainless electrode is high, it is advisable to use electrodes shorter than usual to avoid overheating of the electrode. A heavily coated electrode should be used. The core wire should be of approximately the same analysis as the plate. Columbium either in the electrode or in the coating is usually used to prevent intergranular corrosion in the case of the 18-8 type. Its value in other grades is questionable.

After welding, discoloration may be noted for a short distance on each side of the weld. This is a surface oxide formed by the high heat of welding. It is regarded as a surface condition and not harmful and can be removed by pickling or grinding and polishing.

A few typical applications have been chosen and the welding procedures outlined for general guidance. A group of photographs of welds in 18-8 stainless steel is shown in Fig. 377.

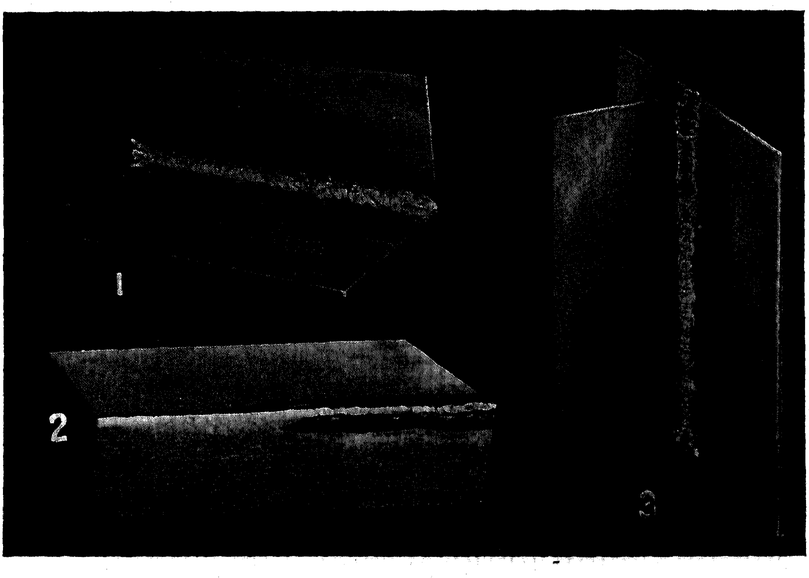


Fig. 377. Welds in 14 gauge stainless steel. (1) Fillet weld, downhand position. (2) Corner weld, portion ground off to show resemblance to parent metal. (3) Fillet weld, vertical position.

The speeds given in these selected procedures or applications are actual welding time only with no allowance for fatigue, cleaning, setting up, etc., as these items vary greatly in different shops.

Any specific application should be studied very carefully and the procedure modified accordingly, taking into consideration such conditions as quality of weld, fit-up and the rate of dissipation of heat for various plate thicknesses.

The pounds of electrodes per foot of weld will, of course, vary with fit-up, bead reinforcement, etc., but data given are for average fit-up, little reinforcement, and include waste, stub ends, etc.

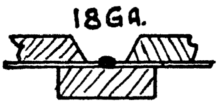


Fig. 378.

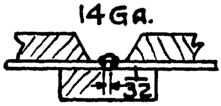


Fig. 379.

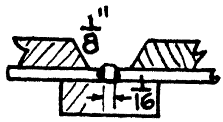


Fig. 380.

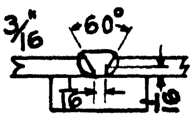


Fig. 381.

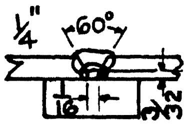


Fig. 382.

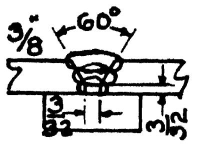


Fig. 383.

BUTT WELDS IN 18-8 AND 25-12 STAINLESS STEEL

Type of Joint & Plate Thickness		Pass No.	Wire Size	Amps.	Volts	Arc Speed		Lbs. Electrode Per Ft. of Weld
						In./Min.	Ft./Hr.	
18 ga.	Fig. 378	1	5/64	45	23	15	75	.020
14 ga.	Fig. 379	1	3/32	60	24	12	60	.038
1/8"	Fig. 380	1	1/8	90	25	9	45	.08
3/16"	Fig. 381	1	5/32	125	26	7	35	.150
1/4"	Fig. 382	1 2*	5/32 3/16	125 160	26 26	6 8	17.5	.34
3/8"	Fig. 383	1 2 3*	5/32 3/16 3/16	125 160 160	26 26 26	6 8 8	12	.51

Note: Copper backing up bar should be grooved approx. 3/16" x 1/16" deep.
* Use slight weave.

Fig. 384.

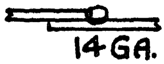


Fig. 385.

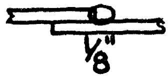


Fig. 386.

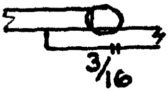


Fig. 387.

Fig. 388.

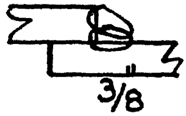


Fig. 389.

Lap Welds in 18-8 and 25-12 Stainless Steel

Type of Joint & Plate Thickness		Pass No.	Wire Size	Amps.	Volts	Arc Speed In./Min.	Arc Speed Ft./Hr.	Lbs. Electrode Per Ft. of Weld
18 ga.	Fig. 384	1	5/64	45	23	13	65	023
14 ga.	Fig. 385	1	3/32	65	24	13	65	.036
1/8"	Fig. 386	1	1/8	90	25	13	65	.056
3/16"	Fig. 387	1	5/32	125	26	10	50	.105
1/4"	Fig. 388	1	3/16	160	26	6.5	32.5	.22
3/8"	Fig. 389	1* 2	3/16 3/16	160 160	26 26	8 9	21.25	.34

*Very slight weave.

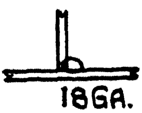


Fig. 390.

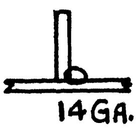


Fig. 391.

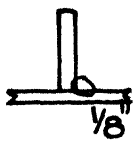


Fig. 392.

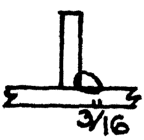


Fig. 393.

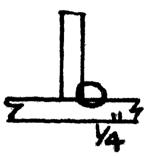


Fig. 394.

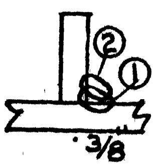


Fig. 395.

FILLET WELDS IN 18-8 AND 25-12 STAINLESS STEEL

Type of Joint & Plate Thickness		Pass No.	Wire Size	Amps.	Volts	Arc Speed		Lbs. Electrode Per Ft. of Weld
						In./Min.	Ft./Hr.	
18 ga.	Fig. 390	1	5/64	45	23	9	45	.034
14 ga.	Fig. 391	1	3/32	60	24	9	45	.052
1/8"	Fig. 392	1	1/8	90	25	9	45	.079
3/16"	Fig. 393	1	5/32	125	26	7	35	.149
1/4"	Fig. 394	1	3/16	160	26	5.5	27.5	.262
3/8"	Fig. 395	1* 2	3/16 3/16	160 160	26 26	5.5 8.5	17.5	.40

*Very slight weave.

Fig. 396.

Fig. 397.

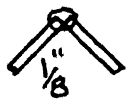


Fig. 398.

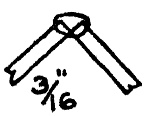


Fig. 399.

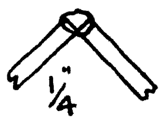


Fig. 400.

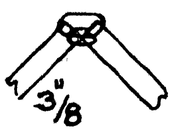


Fig. 401.

Fig. 402.

Fig. 403.

Fig. 404.

Fig. 405.

Corner Welds in 18-8 and 25-12 Stainless Steel

Type of Joint & Plate Thickness		Pass No.	Wire Size	Amps.	Volts	Arc Speed In./Min.	Arc Speed Ft./Hr.	Lbs. Electrode Per Ft. of Weld
18 ga.	Fig. 396	1	5/64	45	23	19	95	.016
14 ga.	Fig. 397	1	3/32	60	24	15	75	.028
1/8"	Fig. 398	1	1/8	90	25	13	65	.057
3/16"	Fig. 399	1	5/32	125	26	11	55	094
1/4"	Fig. 400	1	3/16	160	26	7	35	.21
3/8"	Fig. 401	1 2*	3/16 3/16	160 160	26 26	8 6	17.5	.40
		Edge Welds in 18-8 and 25-12 Stainless Steel						
18 ga.	Fig. 402	1	5/64	45	23		100	.015
14 ga.	Fig. 403	1	3/32	60	24		90	.025
1/8"	Fig. 404	1	1/8	90	25		75	.047
3/16"	Fig. 405	1*	5/32	125	26		60	.087

*Very slight weave.

Vertical Welding of Stainless Steel

Vertical welding is generally recommended welding up. Technique similar to that for mild steel welding should be followed. Use size electrode and current shown.

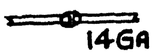


Fig. 406.

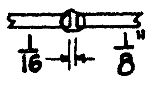


Fig. 407.

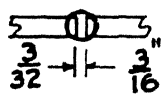


Fig. 408.

Fig. 409.

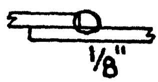


Fig. 410.

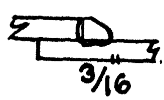


Fig. 411.

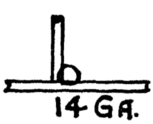


Fig. 412.

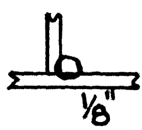


Fig. 413.

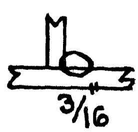


Fig. 414.

Type of Joint & Plate Thickness		Pass No.	Wire Size	Amps.	Volts	Arc Speed		Lbs. Electrode Per Ft. of Weld
						In./Min.	Ft./Hr.	
BUTT WELDS VERTICAL								
14 ga.	Fig. 406	1	3/32	50	24	8.5	42.5	.041
1/8"	Fig. 407	1	1/8	65	25	6	30	.087
3/16"	Fig. 408	1	1/8	65	25	3.5	17.5	.150
LAP WELDS VERTICAL								
14 ga.	Fig. 409	1	3/32	50	24	6	30	.058
1/8"	Fig. 410	1	1/8	65	25	5.5	27.5	.091
3/16"	Fig. 411	1	1/8	80	25	5	25	.123
FILLET WELDS VERTICAL								
14 ga.	Fig. 412	1	3/32	50	24	4.5	22.5	.092
1/8"	Fig. 413	1	1/8	65	25	4.5	22.5	.120
3/16"	Fig. 414	1	1/8	80	25	4	20	.151

Overhead Welding — In general the same preparation, fit-up and currents as used in vertical welding apply to overhead welding with the exception that the weld is made generally with a number of straight beads. Care must be taken to clean thoroughly all slag from each bead before another is applied.

Stainless Clad Steel

Stainless clad steel is a ply material having a thin surface of true stainless steel, usually about 20% of the total thickness, on a foundation of soft or mild steel. It was developed to provide the corrosion-resisting advantages of solid stainless steel at a reduced cost.

It is evident that if a sheet or plate has a thin surface of the relatively costly stainless steel, the bulk of the sheet or plate being ordinary steel, the cost of the stainless clad product will be much lower than if it were made up entirely of solid stainless steel. On this basis stainless clad steel has found acceptance for many applications where the corrosion resistance of stainless steel is desired, but where the economy of the clad steel dictated its use.

Three typical stainless steel analyses include regular 18-8 Low Carbon Type 304; 18-8 Columbium bearing Type 347; 18-8 Molybdenum bearing Types 316 and 317. Many other analyses are also regularly supplied. (See Page 300 for analyses.)

The regular 18-8 type 304 analysis is used on a great many applications. Where the corrosion resistance of type 304 does not meet the service requirements, another type, such as 316, 317, or 347 may be used.

The Columbium-stabilized type 347 is used for applications where equipment must operate in the presence of elevated temperatures in combination with corrosion conditions. It is also desirable for parts that must be heated for forming in the process of fabrication.

The selection of the type or analysis to be used must be given careful consideration inasmuch as the performance of equipment depends upon it directly. (See Page 300).

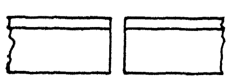
The physical properties of stainless clad steel are a combination of the physical properties of the two metals—mild steel and stainless steel—which form the combined sheet or plate.

Metallic Arc Welding—Two sides are to be welded, the stainless side and the steel side. When welding the stainless side of stainless clad by the metallic arc method, the electrode should be positive and the work negative (reversed polarity). Electrodes should be of the proper analysis for the cladding being welded. In the case of the 18% chrome-8% nickel cladding it has been found that the 24% chrome-12% nickel electrode offers a corrosion resistance equal to or superior to that of the stainless surface. However, the 18% chrome-8% nickel electrode (with a carbon content not to exceed .08%) has been successfully used. When welding sheets thinner than 3/16" it is advisable that the electrode have a higher alloy content than that of the material being welded.

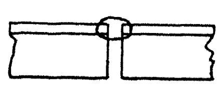
Welding Stainless Steel to Mild Steel—Generally an electrode of 25-12 analysis is used. A good general purpose shielded arc electrode steel is also used in some cases with excellent results. It must be recognized that some place in the joint there is a transition from the stainless steel to steel.

Make the weld bead in multiple passes to minimize the amount of dilution on the surface of the bead. Where it is required that the weld be made in one pass, the use of 25-12 electrode is to be preferred because it gives a deposit of high ductility.

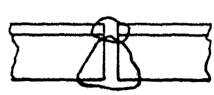
In cases where general purpose shielded arc electrode has been used in multiple passes, it has been found to be very ductile. In the case of a single pass, it may be effected by the inwash of the parent metal. Both methods have been used successfully.



(a) Good results may be obtained with spacing same as for steel sheets of same thickness between edges.

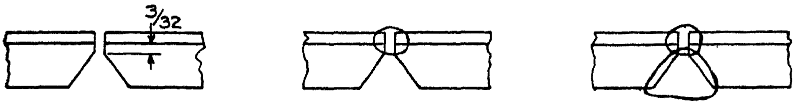


(b) Weld from stainless side first with 25-12 electrode. Maximum fusion between edges is required.



(c) To complete joint—weld from steel side (stainless electrode 25-12).

Fig. 414-A. Recommended procedure for welding stainless clad 12 gauge and thinner.



(a) Edges are beveled by chipping or grinding. Approximately 3/32 of mild steel shoulder is left under cladding. Spacing plates as for steel of same thickness.

(b) Weld first from stainless side using stainless electrode and obtaining good penetration and fusion.

(c) Complete joint by welding on mild steel side using shielded electrode for mild steel.

Fig. 415. Recommended procedure for welding stainless clad No. 10 gauge to 3/16.

(a) "U" groove similar to mild steel groove for same thickness plate leaving 3/32" shoulder of mild steel back of cladding.

(b) Double "V" groove — Note point of bevel and larger level is in mild steel.

(c) Weld steel side first, multiple beads mild steel shielded arc electrode.

(d) Chip with pneumatic hammer or grind with narrow rubber bonded wheel.

(e) Complete joint by welding stainless side with stainless electrode.

Fig. 416. Recommended procedure for preparation of 3/8" and heavier stainless clad plate—planing equipment being used.

The amperage used for welding the stainless steel surface should not be excessive. Generally somewhat lower than for steel electrode (shielded) of same diameter. Consult Procedures on 18-8 and 25-12. (Pages 303-309.) Excessive amperage will cause overheating of sheet in weld area, and overheating of welding electrode. Extremely low amperage will cause slag inclusions and lack of fusion. It is advisable to make trial welds before beginning a job because prevailing conditions, analysis, type of coating, amount of coating, length of electrode, etc., have definite bearing on the amperage required for each diameter of electrode.

The required electrode diameter for various sheet and plate thickness is approximately as follows:

5/64" for sheets under No. 14 gauge
3/32" for 16 gauge to 1/8"
1/8" for 1/8" to 1/2"
5/32" for 3/16" to 1"

When welding the lighter gauges of stainless clad it is advisable to use chill bars wherever possible, since it is necessary that the weld and adjacent metal cool quickly. On heavy material this is not necessary because the mild steel backing acts effectively as a chill.

Since mild steel normally comprises 80% of the total thickness of stainless clad, the heat is dissipated more rapidly than would be the case in like gauges of solid stainless steel sheets or plates, due to the relatively high heat conductivity of mild steel. This natural advantage of stainless clad steel combined with the low carbon content of the stainless surface eliminates, in practically all cases, the necessity for heat treatment after welding.

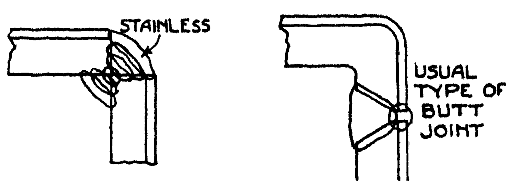
Welding of Mild Steel Side—In welding the mild steel side of stainless clad plate it is desirable to weld with multiple beads to avoid overheating of stainless surface. Except where the most severe corrosion conditions exist it is not necessary to heat-treat stainless clad after welding if the proper care is taken in welding.

General purpose shielded arc electrode is recommended.

Vertical Welding—Stainless clad may be welded in the vertical position with no great difficulty. Sheet stock will usually have to be welded by starting at the top and welding downward, while heavier plates may be welded starting at the bottom and welding upward.

Design and Preparation—Design and preparation for welding have much to do with the cost and the quality of weld deposits (see Page 205). By employing proper designs, it is possible to reduce materially welding labor and amount of stainless steel electrode may be held to a minimum. Note the comparison—Fig. 417 (a) and (b).

In all cases joints should be designed so that iron pick-up will be minimized and localized. Where steel is exposed as in the case of lap and corner welds, it is best to apply a stainless weld in several layers. Note. Fig. 417 (a) This condition may be eliminated in many cases; see Fig. 417 (b).



(a) Welding procedure to reduce iron pick-up in improperly designed corner. Note multiple beads of stainless weld necessary at corner.
(b) Method used to avoid corner weld.

Fig. 417. Procedure for corner welds.

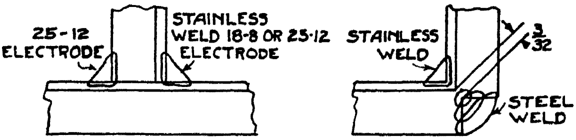
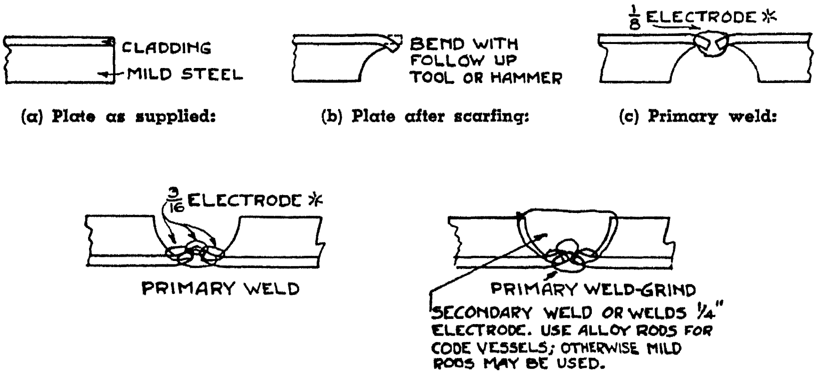


Fig. 418. Welding procedure for right angle intersections in construction of stainless clad tanks.

On poor fitups or where it may be necessary to deposit a weld bead joining stainless and steel, use stainless electrodes, for entire joint.

Another method for welding stainless clad is outlined in Fig. 419.



(a) Plate as supplied: **(b) Plate after scarfing:** **(c) Primary weld:**

(d) Secondary weld: **(e) Final weld, or welds:**

Fig. 419. Alternate method for welding stainless clad.

*In all cases use rods richer in alloy than the cladding. For example, on Type 304 use Type 317 rod. Keep amperage as low as possible and weld as fast as possible.

Welding of Galvanized Steel

The welding of those corrosion resistant materials, known as galvanized steel, which is a steel coated with zinc, presents a problem which at first sight appears a bit difficult. However, experience and investigations indicate that welding galvanized steel affects the strength or corrosion resistant qualities much less than commonly thought. For all practical purposes its effect is negligible. Note that in threading a pipe, galvanizing is removed, and the section is reduced at the joint.

The reason for this is the fact, not generally known, that the zone from which the coating or galvanizing appears to have been removed by the heat of the arc has little reduction in its corrosion resistant properties. It is, of course, obvious that the heat of the arc will melt the zinc, and that some of the zinc goes off in fumes—a greater removal being next to the bead. But even this very small or narrow zone of what appears to be complete removal of zinc, is not attacked as an ungalvanized steel would be. In the zone where the zinc is melted, and this zone may occur at some distance from the bead, the protection is not reduced. The extent of this zone depends upon the thickness of the plate, current used, and may be several inches.

Multiple beads burn off the zinc to a greater degree, have less porosity and slightly more strength than single beads. But in the case of multiple beads the effect is negligible.

Large multiple bead fillet welds are not so corrosion resistant; whereas small single bead fillet welds are practically equal to the base metal, galvanized steel.

These facts indicate clearly that galvanized steel may be welded, without affecting the galvanizing to any great extent.

As mentioned above, the heat of the arc liberates zinc fumes. Provision should be made for protection of the operator from these fumes, by proper ventilation (see Page 22). This precaution should be taken at all times and for every job involving galvanized steel.

Metallic Arc.—Procedure for welding galvanized steel, using mild steel shielded arc electrode, is the same as is usually used for ordinary mild steel. (See Page 179).

Carbon Arc.—The following procedure is for the welding of galvanized sheets from 16-to-22-gauge inclusive, by the carbon arc process with a copper alloy filler metal. For 16- and 18-gauge the $3/32''$ diameter filler metal is used and $5/32''$ carbon. For 20- and 22-gauge the $1/16''$ diameter filler metal is used and a $5/32''$ carbon.

Carbon electrodes should have a long thin taper. Take a standard $5/32''$ carbon and grind it down with a gradual taper to a very small point. This is held in the electrode holder about $1\frac{1}{2}''$ from the point so that during operation it will keep itself necked down and tapered.

The current will range from 50 amperes for the 16-gauge down to 20 amperes for the lighter gauges depending upon the type of joint being made.

The filler metal used is a copper-silicon-manganese alloy, such as "Everdur", "Herculoy", "Olympic Bronze", etc., or similar materials.

Lay the filler metal on the plate in the joint at about a 10° angle as shown in Fig. 420.

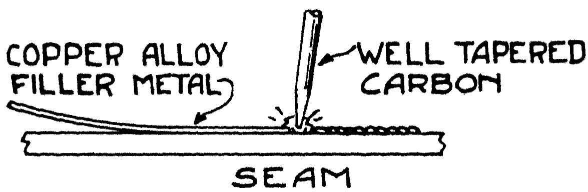


Fig. 420.

Strike the carbon on the plate at any place and hold it in position until it becomes incandescent. This permits sufficient illumination so that carbon may be slid along the plate without establishing an arc until the carbon reaches the end of the filler rod. This reduces greatly the possibilities of making a false start and damaging the parent metal.

A very short arc should be held. The arc should always be played on the filler metal and not on the galvanized sheet. The arc should be so short that it may at times appear as if there is no arc at all. In other words,

it should be as short as it is possible to hold without the arc breaking. The arc will be found easy to hold, and can be advanced along the seam without any difficulty. If the proper current and arc length are used, extremely smooth welds will result.

Some types of joints weld better with this method than others, the relative ease being (See Fig. 421.):

1. Offset lap (A)
2. Lap (B)
3. Butt (C)
4. Outside corner (D)
5. Inside fillet (E)

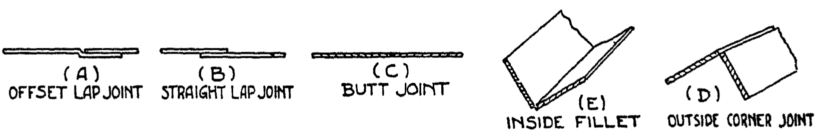


Fig. 421.

The best joint is obtained by running one of the sheets through a roll, or press brake, to get an offset lap as shown in (A). With this type of joint the weld metal flows very readily, and has a further advantage on sheet metal work of acting as a stiffener and reducing, to a very noticeable extent, the effect of warping.

On other work, the above mentioned type of joint may be too expensive and it may be necessary to use a straight lap as shown in (B). In this case, tack the edges together with the same process every few inches before starting to actually weld the seam. This will prevent the seams from opening up as the welding progresses.

Properly done, carbon arc welding of galvanized sheet results in a joint of high physical characteristics, and corrosion resisting property.

Keep the heat low so that the galvanizing is not disturbed. Also be sure to play the arc on the filler metal, rather than the sheet.

Carbon arc welding with copper alloy filler rod may be applied not only to galvanized sheets but also to ordinary blue-annealed sheets of thin gauge or where the gap prevents the use of metallic electrode with a reasonable degree of ease. The process will be found effective on such items as welding of fenders (see Page 779), and miscellaneous body work on cars. Excellent results are obtained because of the very low amount of warpage.

An improvement on the standard copper alloy method outlined above is that of a patented method employing the carbon arc with copper alloy, *tin-coated* filler rod. With proper procedure, this method covers the heat zone of the weld with molten tin (melting point 231° C., volatilization point 2260° C.), protecting the zinc (melting point 419° C., boiling point 907° C.) while the copper alloy rod (melting point 1020°-1240°C.) is being deposited. The resultant coating of zinc and tin alloy along the weld provides added corrosion resistance.

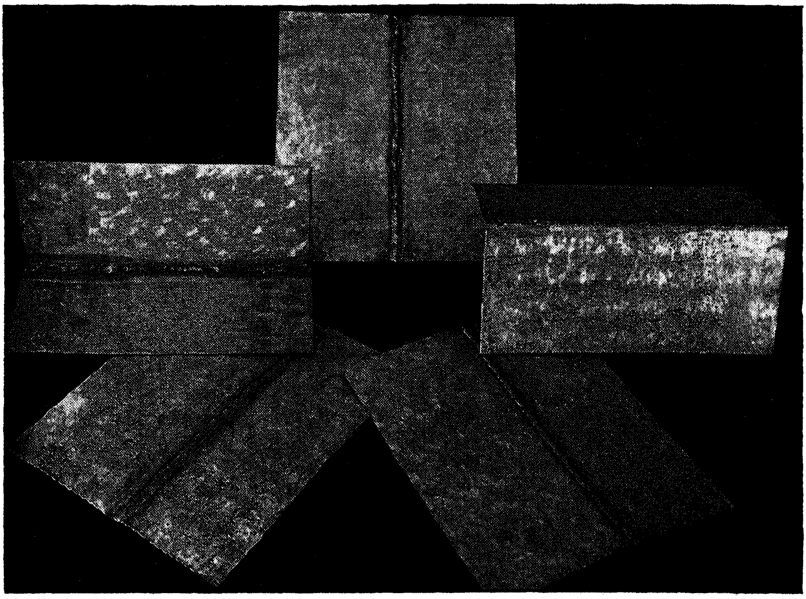


Fig. 422. Galvanized sheets welded by the carbon arc process.

Carbon arc welding assures improved appearance and greater strength for thin-gauge applications such as ductwork. (See Page 1025). A few weld specimens are shown in Fig. 422.

Chromium Steel

It is well to have a thorough understanding of this type of steel, its uses and physical characteristics.

Steels containing 4% to 6% chromium are not stainless steel although classified as such by many people. This is due, no doubt, to the fact that such steels possess a resistance to sulphide corrosion by laboratory tests of four to ten times that of ordinary steel, and resistance to oxidation at 1000 degrees F. three times as great, and various types of installations from this alloy have verified these experiments. It is, therefore, finding increasing use in the form of furnace tubing, cracking stills, hot oil transfer lines, heat exchangers, bubble tower caps, return bends, valves, and in the form of plates for fabrication.

Physical properties of the 4-6 chromium alloys develop some interesting possibilities. In the first place, this steel can be soft annealed to physical properties similar to those of mild carbon steels, and therefore it is suitable for equipment where severe cold work is applied during fabrication. On the other hand, some steels with remarkably high yield points and tensile strengths, combined with excellent ductility and impact toughness, can be produced by simple air hardening treatments. It is obvious that many articles, so shaped that quenching in liquid media is difficult, might be produced from steels containing 4% to 6% chromium, and subsequently heat treated, without excessive distortion, to the desired properties.

Air Hardening: The most noticeable property of the 4-6 chromium steels is their intense air hardening which is proportional to both the carbon and chromium contents. This factor must be considered in all operations involving the use of these materials where reheating occurs, such as welding, Van Stoning, hot bending, forging. After such operations, the metal should be annealed by heating to a temperature of 1575 degrees F. and cooled back in the furnace, or reheated to a temperature of 1400 degrees F. for several hours depending upon the thickness of the section. In welding, the metal should be annealed as soon as possible after the welding operation, not only in the welded metal but also in the zone on either side of the weld. The fully annealed material, however, can be bent, flanged, and expanded cold almost as readily as low carbon steel.

Carbon very noticeably affects the various physical qualities of this group of steels.

The American Iron and Steel Institute has issued a list of standard type numbers of stainless steels and analyses applicable thereto which contains the following (in per cent):

Type No. 501 A—Chromium 4.00 to 6.00; carbon 0.21 to 0.25
Type No. 501 B—Chromium 4.00 to 6.00; carbon 0.16 to 0.20
Type No. 501 C—Chromium 4.00 to 6.00; carbon 0.11 to 0.15
Type No. 501 D—Chromium 4.00 to 6.00; carbon 0.10 max.

The air hardening effects on these steels with varying carbon content are illustrated in the following table:

TENSILE PROPERTIES OF 0.505-IN. STANDARD BARS

Carbon	Chromium	Air Cool	Draw	Yield Point	Tensile Strength	Elongation	Reduction	Hardness	Izod Impact
0.10	5.20	1600°F.	None	108,860	181,420	15.5	53.2	361	23.0
0.20	5.20	1575°F.	None	114,000	212,310	9.0	18.5	417	23.0
0.30	5.30	1575°F.	None	118,200	222,100	13.5	31.7	448	16.9
0.10	5.20	1600°F.	1110°F.	102,180	114,100	20.0	71.0	250	76.4
0.20	5.20	1575°F.	1110°F.	120,100	137,600	18.5	58.7	272	36.0
0.30	5.30	1575°F.	1110°F.	116,840	137,400	18.0	60.5	275	59.1
0.10	5.20	1600°F.	Furnace cooled	27,300	62,030	37.5	75.6	136	84.2
0.20	5.20	1575°F.	Furnace cooled	33,200	75,600	32.0	75.0	152	84.1
0.30	5.30	1575°F.	Furnace cooled	34,600	79,200	31.5	73.6	161	79.3

The air hardening effects described above are best exhibited in the physical properties noted in the table. These figures indicate the very high yield points and tensile strengths that come from simple air hardening or air hardening and drawing, which treatments are quite as effective as the quenching of ordinary steels in liquid media. Combined with high tensile strength, the alloys also exhibit great ductility and impact toughness. The impact properties and elongation of these alloys are, in many cases, superior to those of some of the best structural alloy steels, when heat treated to the same yield point and tensile strength.

Another peculiar physical property which these alloys exhibit is that in the air hardened condition and in the fully annealed condition, the elastic ratio is low, often being less than 50%, whereas the air hardened and tempered material shows very high elastic ratios, usually over 80%.

It will be noted also that the carbon content has an appreciable effect on the yield point and tensile strength, especially on the soft annealed material. In applications where this alloy is to be used for high temperature service, such as cracking still tubes and condenser tubes, and where flanging, rolling and other manipulations are required, only soft annealed material should be employed. Exposure of semi-annealed material for long times at temperatures between 800 degrees and 1200 degrees F. gradually produces the effect of a soft anneal.

Fig. 423. V-groove butt joint in 3-inch pipe of 4-6% chromium steel.

The previous discussion refers chiefly to the 4-6 chromium alloy groups without other alloy additions. The addition of various alloys such as molybdenum, tungsten, titanium, produce various satisfactory results and are used in many cases where the application makes desirable the qualities which these various other alloys give to this group.

Probably the most commonly used additional alloy is molybdenum, usually in an amount of approximately 0.5%. This addition of molybdenum does not appreciably effect the physical qualities of the steels at room temperatures, and after the different heat treatments, but it does increase to a considerable degree the strength of these steels at elevated temperatures and, according to some tests, increases the resistance to certain types of corrosion. This increase in strength at higher temperatures is known as an increase in creep strength.

One per cent tungsten has somewhat the same effect but increases the tensile strength somewhat at room temperature. Tungsten, being a relatively scarce alloy, however, usually increases the cost.

Electrodes are available for welding the above steels which contain molybdenum. The weld deposit possesses the higher creep strength, and other desirable qualities.

Bearing in mind the general characteristics of 4-6 chromium steel and its air hardening qualities in particular, considerable care should be noted in regard to the suggestions for keeping the material to be welded warm during welding and its annealing afterwards, because if this is not done the welds, and particularly the area adjacent to the weld, will be quite brittle and will withstand but very little stress, particularly bend stress.

11-14% Chrome—.12 Max. Carbon: This steel is subject to air hardening and grain growth with resultant brittleness and low impact strength. The carbon in the base metal should be kept as low as possible as this has considerable effect on impact strength.

Immediately after welding anneal at 1200 degrees to 1450 degrees F. A 17% chrome electrode is suitable for welding this steel, or an electrode of 18-8 type may be used.

It must be carefully noted that the coefficient of expansion of 18-8 metal is from 40% to 60% greater than steel. This must be taken account of in design in the location of joints, the relative restraint thereof, particularly in those cases where repeated heating and cooling is encountered, when an 18-8 electrode is used.

15-17% Chrome—.12 Max. Carbon: This steel, as the preceding one, is subject to grain growth and is very brittle if not annealed. It should be heat treated for impact and toughness. Preheat to 200 degrees to 250 degrees F., which may be done locally—weld—then anneal at 1200 degrees to 1450 degrees F.—slowly cool to 1100 degrees F.—and to obtain best results air cool below 1100 degrees F. The chromium should be kept on the low side for best weldability, with a 17% chrome electrode. An 18-8 chrome-nickel electrode may sometimes be used, keeping in mind the precautions mentioned under the 11-14% chrome.

18-20% Chrome—.12 Max. Carbon:

25-30% Chrome—.30 Max. Carbon: These are not air hardening but are subject to grain growth. They are very weak and brittle in and next to the weld. The coarse grain cannot be eliminated by heat treatment. They should be preheated to 500 degrees F.—weld and anneal at 1450 degrees—and allow to air cool. A 25-30% chrome electrode may be used, or a 25-12 chrome-nickel electrode.

Note that when 18-8 or 25-12 chrome-nickel electrodes are used to weld the straight chrome alloys, it is necessary to use a stabilized electrode if the work is to be heat treated after welding, otherwise the corrosion resistance of the weld metal will be poor. The type of service should be investigated before using a chrome nickel electrode on straight chrome material. Under some conditions a straight chrome steel is more satisfactory than the chrome nickel alloy.

It is well to consult the supplier for specific heat treatment, temperatures and treatment.

4-6 Chrome can be successfully welded by using an electrode developed particularly for it. Since the metal has a tendency to harden when exposed to the air after heating, welding should be done in accordance with the following procedure.

The welding is done with the electrode positive and work negative. Currents and voltages, somewhat lower than those employed in welding other steels by the shielded arc process, are used. The following table is given as a guide.

Size of Electrode	Suggested Current to be Used	Suggested Voltage to be Used
1/8"	75 to 100 amperes	22–23
5/32"	100 to 150 amperes	24–25
3/16"	125 to 200 amperes	26–27

The material to be welded should be purchased in annealed condition.

The parts to be welded should be preheated to between 400° and 500° F. to prevent cracking during welding. In no event should preheating be less than 300° F. The work should not be allowed to fall below this temperature at any time. Immediately after welding—and before the work is allowed to cool—it should be placed in an annealing furnace. Anneal at 1550° to 1600° F. and cool slowly. Temperature of the work should not drop over 50° F. per hour. When the temperature has dropped to 1200° F., the work may be taken out of the furnace and allowed to cool in the air. Instead of the 1550° to 1600° F. anneal, the work may be annealed at 1400° F. When stress annealed, the weld metal will possess the following physical properties:

Ultimate tensile strength	65,000-70,000 lbs. per sq. in.
Yield point	35,000-40,000 lbs. per sq. in.
Ductility, elongation in 2"	35-40%
Reduction of area	65-75%
Hardness (Brinell)	130-140

When stress relieved the weld metal will have the following physical properties:

Tensile strength	80,000-90,000 lbs. per sq. in.
Yield point	55,000-65,000 lbs. per sq. in.
Ductility, elongation in 2"	24-30%
Reduction of area	60-70%
Hardness (Brinell)	155-175

4-6 Chrome Steel, due to its characteristics, should be used with caution where it is not possible to heat treat after welding. Severe loads should not be placed on the work before heat treatment since the metal is brittle in the unannealed condition.

High Manganese Steel

High manganese steel contains about 12% to 14% manganese and 0.50% to 1.25% carbon. It is very tough and hardens on cold working. For this reason it is used where resistance to wear or abrasion is highly essential, also, where high strength and shock resistance are desired; for example, parts of rock and ore crushing machinery, parts of power shovel buckets, railroad frogs and crossings and similar parts.

For building up worn parts of high manganese steel an electrode should be used of such type that the physical characteristics of the deposited metal will be approximately the same as the base metal. The weld metal should be air toughening, i. e., it remains in austenitic state even on slow cooling. Water quenching should therefore be avoided because it would set up localized cooling strains which often result in checks in the weld and its subsequent failure. The weld metal as deposited should be comparatively soft; and after cold working, should have a hardness of 46 to 50 Rockwell C.

Reversed polarity should be used when welding with type of electrode indicated previously. The exact heat to be used depends upon the mass of the part being built up; more heat being required for heavy sections than for thin sections. Both shielded arc and bare electrodes are available for this work. The bare electrode is distinctive for its relatively high beads, minimizing the number of passes. The shielded arc electrode gives a flat bead desirable for surfacing with minimum grinding. Suggested amperages for various sizes of electrodes are as follows; in general the lower currents should be used so far as possible.

Electrode Size	Amperage	Arc Voltage
$\frac{5}{32}''$	90-130	24
$\frac{3}{16}''$	130-170	26
$\frac{1}{4}''$	170-225	26

Fig. 424. Beads of high manganese steel. Left: with shielded arc electrode. Right: with bare electrode.

The part to be built up must be free of all rust, spongy or defective material. This cleaning can be done by proper amount of grinding. Wherever possible the welds should be placed in pads, $\frac{1}{2}''$ to $1''$ wide, preferably not more than $3''$ in length. Long narrow beads should be

avoided. Precautions should be taken, however, to avoid localized heating of manganese steel castings. Pads should be so placed that the heat is well distributed throughout the casting. If necessary the *casting only* but not the weld, should be cooled with water periodically to prevent distorsion and possible cracking of the casting. Hammer the surface of the pad immediately while it is cooling. This peening stretches the metal and relieves the cooling strains. Use the lowest heat possible consistent with good fusion. Give the parent metal time to absorb the heat from the area of welding and to cool between beads. Clean off all slag and brush area where next pad is to be deposited.

For welding up cracks in high manganese steel, or for welding high manganese steel together, or a part to mild rolled steel, a heavily coated metallic electrode of austenitic steel should be used. The use of this type electrode gives the weld a high tensile strength. The procedure for welding is similar to that for welding chrome-nickel steel (see Page 303). In such cases where abrasion-resistant surface is required the top beads should be applied as described for building up worn high manganese steel parts with the type electrode prescribed for manganese work.

Lead-Bearing Steels

By suitable methods, lead may be suspended in steel in small amounts. Lead does not go into solution, being practically insoluble in liquid or solid steel. The lead which is in a very fine state, improves the machinability of the steel. It does not, however, greatly affect the physical properties of the steel nor its heat treatment qualities.

Lead-bearing steels may be welded readily, using Type A or Type C electrodes (see Page 148). Work should be done in a well ventilated space, preferably with dust removing equipment. Behavior of the metal is similar to that of semi-killed steel of corresponding carbon content. A very small amount of fine porosity may result, but welds are of high quality. Welding characteristics are good.

Typical results for reduced section are as follows:

	Tensile (lbs./sq. in.)	Yield (lbs./sq. in.)
As welded	74,150	55,600
Stress relieved	69,500	42,600

Fractures are normal for steel of similar analysis without lead.

High Carbon Steel

Carbon for the usual steels is one of the most important and most powerful alloying elements. It may be present in amounts very small as .08% or as high as .8% to 1.00% or more. (The carbon content is sometimes expressed in points—which are hundredth of per cent. For example—a 20 point carbon steel has .20% carbon in it.)

All of the steels may be arc welded except those of very high carbon content such as spring steel .75% to 1.00% and tool steel .90% to 1.65%.

The higher the carbon content of steel, the harder it becomes when it is quenched from above a certain temperature called the critical temperature—assuming that the rate of cooling is constant. It is well to remember that the critical temperature for .10 C steel is about 1600 degrees F. whereas that for 1% C steel is about 1400 degrees F. Up to about .15 or .20 carbon very little hardening is obtained if quenched in water from above its critical temperature. Steel of 1% carbon will have a hardness of more than 700 Brinell if quenched in water from above its critical temperature. This material has practically no ductility.

It is also true that for a given carbon content, the faster the rate of cooling, or quenching (up to a certain limit) the harder the steel becomes. As a specific example, if .85 C steel is heated to 1450 degrees F. and cooled very slowly an annealed structure will result which will probably run around 250 Brinell. If cooled from 1450 degrees F. in still air, the hardness will be approximately 300 Brinell. If quenched in oil, about 450 Brinell and if quenched in water, about 600 Brinell. Quenching in iced brine would increase the hardness still more.

If a bead is deposited on a steel plate the temperature of the parent metal is raised. The temperatures vary, ranging from its melting point at the fusion zone down to perhaps no increase at all some distance from the bead. There will be a zone in the parent metal adjacent the bead which has been heated to the critical temperature or above and the thickness of this zone (when welding on cold plate) will depend on the heat input and thickness, or mass of metal on which the bead is deposited Using $\frac{3}{16}''$ wire at 200 amps. with a normal rate of travel, this zone may be $\frac{1}{8}''$ thick on $2''$ plate and $\frac{1}{2}''$ thick for $\frac{1}{4}''$ plate.

It is this zone in the parent metal that cracks—not because it is weakened, but because it is hardened to the point where its ductility is reduced to such an extent that it cannot stretch. This is analogous to "quenching cracks" which are often encountered in heat treating high carbon steel.

It is not appreciated generally that when a bead is run on a thick, cold plate, the cooling rate of the parent metal adjacent the weld is about the same as by quenching it in water, because the cold metal conducts the heat away very rapidly.

Preheating the parent metal seems to be the only practical method of eliminating this hardened zone in high carbon steel. The effect of preheating in connection with the building up of battered rail ends, which are about .80 carbon steel, has been studied. A bead deposited on a cold rail will result in a hardening of the parent metal adjacent to the deposit. The hardness of the original rail will be about 250 Brinell and the hardness of the parent metal just under the deposit will be about 600 Brinell regardless of the type of rod used or the hardness of the metal deposited. If, however, the rail end is heated to 400 degrees F. and then the bead deposited on it, the hardness of this zone will be about 325 Brinell. The difference is in the rate of cooling from the critical temperature. The material which has a hardness of 600 Brinell will have a tensile strength in excess of 300,000 pounds per square inch and practically no ductility while the 325 Brinell material will have a tensile strength of

about 150,000 pounds per square inch and elongation of perhaps 10 to 15% in 2 inches, which, in this case, is sufficient to stretch without cracking.

Assume that some high carbon parts which are to be welded together are firmly restrained and the cooling rate is high, resulting in low ductility. It is evident that cracks will probably result.

This suggests a method of joining these two parts in order to make the weld metal sufficiently ductile to withstand this contraction.

This procedure comprises:

(1) Control of the heating and cooling conditions.
(2) Proper procedure.
(3) Use of intermediate beads.
(4) Use of special electrodes.

(1) Preheat the parts to 400 degrees F. or even higher—to 500 degrees or 600 degrees F. Weld while hot and then cool very slowly—as in a furnace overnight. The higher the carbon the slower the cooling should be. Steel of .30% to .40% carbon content may be welded as ordinary steel allowing two or three hours to cool, if practical. For steel above .40% carbon all-night cooling is recommended. Use a Type B (see Page 192) mild steel shielded arc electrode.

Enough metal must be deposited in one pass so that there will be sufficient cross-section to take care of stresses caused by contraction. Particularly in reference to first bead.

If the cross-section of the first bead is too small, when it contracts the unit stress will be sufficiently high to cause fracture. This condition is most liable to occur in fillet or lap joints.

(2) Select proper type of joint. In lower carbon ranges (up to .25%) the type of joint is not so important. Above this, however, due to admixture of base metal into bead, it is important. If the two parts to be joined are firmly fixed then if the bead is not ductile, it may fail.

In this case it is advisable to scarf rather than use plain butt joint to keep the admixture to a minimum and thereby obtain maximum possible ductility.

(3) For higher carbon content than .25%, an intermediate bead is frequently used. For example, the single vee butt joint shown in Fig. 425.

Fig. 425.

A layer or two layers of Type B (see Page 192) shielded arc electrode are used. The result is the surfaces are relatively low in carbon and may be joined by a low carbon electrode of the above type, just as any joint is made. It must be clearly understood that the joint is not high carbon.

(4) For steels above .30% carbon an 18-8 stainless steel electrode gives a joint with excellent physical properties and good fusion.

Where the heating conditions can be controlled, a high carbon steel electrode (approximately 1.0%) may be used. In this case the carbon may be controlled to some degree by the arc length.

From the foregoing, it is evident that the best procedure for the higher carbon steels well above .30% is to heat above 500 degrees F.—weld while hot and let cool slowly. For carbon content of .30% to .40% —methods such as intermediate beads, special electrodes as previously described may be used.

No matter what type of electrode is used, brittleness will occur in the base metal if the carbon or alloy content in the base is too high and it is cooled too fast. The properties of the deposit may be controlled by electrode composition but brittleness in the affected zone of the base is controlled by heat (cooling rate) and by the chemical composition.

Medium High Carbon Steel

Steel having a carbon content of 40 to 50 points, medium high carbon, has a high ultimate strength (see Page 291), but when cooled rapidly, as in the usual welding process, it becomes rather hard and brittle in the cooled zone. This may result in cracks in the surface of the base metal and in the bead at this point of cooling. These cracks are objectionable because they cause an uneven distribution of stress in the sections affected. (See Page 75).

Therefore it is necessary to retard the rate of cooling of this metal. This may be done by preheating, keeping the joint hot while welding and cooling slowly. Upon completion it should be stress relieved, annealed, or subjected to suitable heat treatment, particularly desirable and necessary for steels in the higher ranges (above 40).

Another method occasionally used is that of depositing a bead of high ductility. It will stretch and therefore not result in cracks. In this case, the bead and joint are not high carbon, but are lower carbon obtained by minimizing the mixture of base metal and deposited metal. This is obtained by using an electrode which gives good fusion but little penetration, generally in conjunction with a scarfed joint.

A modification of this method consists in depositing on each part of a joint with rather wide scarf joint, a layer or two of bead. The object here is to keep the carbon content low in the first bead and even lower in the second bead. The two parts can then be joined by welding the two beads together, resulting in a low carbon, ductile joint.

These first layers, or beads, may be deposited on this steel by a usual shielded arc electrode or a stainless steel (18-8) electrode. The joint can be completed with the usual shielded arc electrode.

The object of this method, which might be termed an intermediate bead procedure, is to obtain a ductile joint by minimizing the in-wash of carbon into the bead. Such a joint is less susceptible to the rate of cooling; it is moderately ductile, being more so than the base metal (40-50 carbon), but not as much as a low carbon joint. The selection of the method of welding depends on the type of load and service the joint is required to meet.

Cast Iron

Cast iron is a complex alloy of six or more elements. The common elements are about as follows: Iron 94—98%, Carbon 2-4%, Silicon 1% or more, Sulphur usually below .2%, Phosphorus usually below .75%, Manganese below 1%; other elements sometimes present in small quantities are copper, nickel, aluminum, titanium, vanadium, etc.

Carbon is the most important element in its effects. It usually exists in two forms, combined chemically with the iron known as combined carbon and free carbon combined mechanically with the iron and known as graphite. It is this graphite carbon which gives the usual grayish appearance to the fractured surface. The ratio of graphitic carbon to combined carbon is usually in the ratio of from 4 to 6 graphitic to 1 combined. Usually an increase of combined carbon increases the hardness. When cast iron cools from a molten state quickly or suddenly, the percentage of carbon in the combined state is increased and the graphite reduced, so quickly cooled cast iron is harder and more brittle than when cooled slowly. This is sometimes called chilled or white cast iron. These facts must be borne in mind as they affect the results of welding materially.

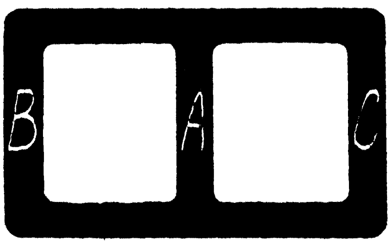


Fig. 426.

When one part of a gray iron casting is heated that part expands and in so doing may throw considerable strain on some other part of the casting; this strain, since the metal possesses low ductility and will not stretch, may be sufficient to break the unheated part. For example, when a casting, such as the one shown in Fig. 426, is heated at A, it will expand at this point and will stress the casting at B and C. It may be stressed beyond its limits and fail at either one of these points or both. Such an occurrence may happen when welding the casting at A, provided parts B and C are not preheated so that the expansion of A, B and C is equal. In such case the casting will expand and contract alike and cause no undue stress in any part.

When preheating is unnecessary or inadvisable, care should be taken not to heat the casting too long or too much at point of welding at one time, but rather a repetition of "weld little and cool much" until the job is completed.

Each job should be studied carefully before welding in order to avoid possible difficulties arising from uneven expansion and contraction of the casting. The heat of the welding arc is confined to a comparatively small

area and for this reason complicated castings offer less trouble when welding is done with the arc than by other methods. It is also for this reason that many gray iron castings can be arc welded in place without dismantling for preheating.

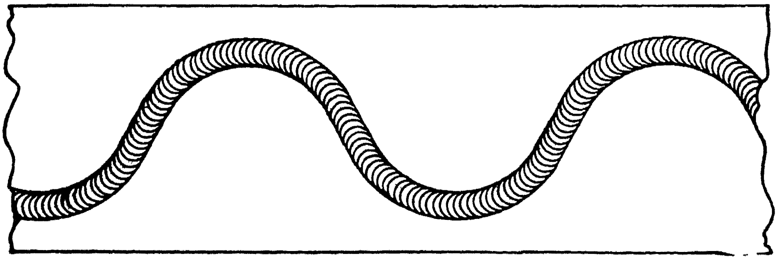


Fig. 427. A method of relieving cumulative strains on cast iron—by depositing weld metal in curved lines.

Cast iron welding may be done with a metallic arc using steel electrodes. A weld of this type is shown in Fig. 429. When using this type of electrode care should be taken in regard to (a) contraction of the weld metal (steel) after deposition, (b) absorption of carbon by the weld metal and rapid cooling which result in hard weld metal.

The shrinkage or contraction of steel from a molten state to a cool state is greater than that of cast iron, going from a molten state to a cold state. Therefore when the molten steel from a steel electrode is deposited on cast iron the steel will shrink more than the cast iron on which it is deposited, causing a residual strain in both the weld metal and the cast iron. A straight bead of weld metal deposited on a horizontal surface of cast iron will be in tension if allowed to cool without further treatment. This is due to the fact that the steel is trying to contract its length by an amount which is proportionate to its change in temperature. At the same time the cast iron on which the weld metal has been deposited will be stressed due to the pulling action of the weld metal on the cast iron. Since the cast iron is weaker, the usual occurrence (particularly when the bead of weld metal is long) is a break in the cast iron just back of the line of fusion.

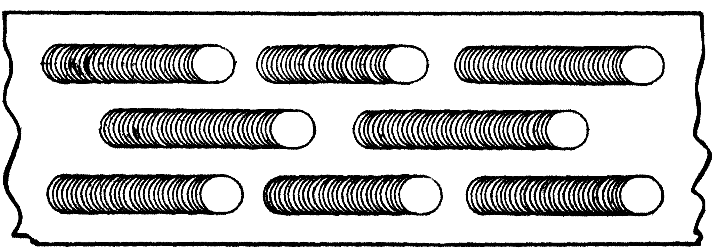


Fig. 428. A sequence of short welds as shown above will help to relieve cumulative strains.

It is evident that the greater the length of the weld in a straight length the more strain, since the strain is cumulative. Therefore if a bead is curved there is a tendency to reduce this cumulative effect.

Another method is to deposit weld metal in short lengths and allow each to cool. For example, weld ½ minute and then allow weld to cool for 3 to 5 minutes. By depositing small welds in various parts of the job one weld is allowed to cool while depositing metal in another location.

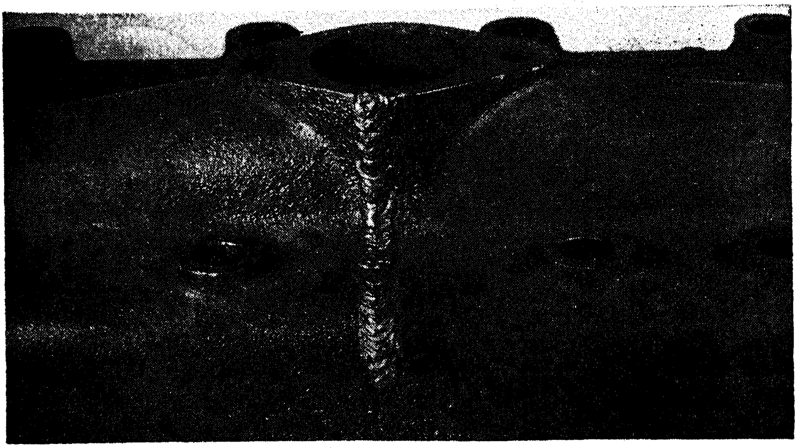


Fig. 429. Weld on engine head made by steel electrode of shielded arc type.

The third method is to upset or peen the deposited weld metal lightly while it is still hot, before it has a chance to cool and contract. This causes the weld metal to stretch. In many cases the best method to pursue is to use a combination of the above three methods.

When steel weld metal is deposited on cast iron of large area and the cast iron being cold with the exception of the weld area, the weld metal and the cast iron in its immediate vicinity are cooled quickly. During the process of welding the deposited metal absorbs carbon from the cast iron. Thus the deposited metal becomes high carbon steel, which when cooled quickly is extremely hard. As previously explained, when molten cast iron is cooled quickly its own combined carbon is increased. Therefore the weld area in the parent metal, when cooled quickly, results in increased hardness of the casting and a tendency to brittleness. Thus in such cases hard, unmachinable material is formed. However, in most repair jobs such a condition presents no difficulties, inasmuch as machining is rarely required. If machining is necessary there are several methods by which the weld metal and weld area in the cast iron can be made machinable; one is to heat the entire casting, or if expansion will cause no difficulty, heat weld and adjacent parts only, to a dark cherry red and allow to cool slowly by covering with asbestos or sand or other heat retention material.

The weld metal deposited by the electric arc process in cast iron is generally far stronger than the cast base metal. When steel electrode is used the weld metal is generally three to four times as strong as the casting.

Coated electrodes of the proper type are usually designed to keep the amount of heat required to a minimum, thus reducing thermal disturbance and resultant hardness.

Usually $\frac{1}{8}''$ size electrodes are used for keeping the heat down as mentioned above. Electrode is made positive, work negative, and current is approximately 80 amp. This apparently too-low current is employed to satisfy the heat conditions previously mentioned. The electrode itself will carry considerably more current but the requirements of cast iron welding make the use of higher heat inadvisable.

The electrode to use in cast iron is a coated electrode with steel base. It provides a solid, dense weld on cast iron of greater tensile strength than the cast iron itself. It affords an excellent bond or union with the cast iron. Because of the low current used, (80 amps. on $\frac{1}{8}''$ electrode), the hardening effect usually present along the line of fusion is materially reduced, the resultant weld being therefore much more machinable than is usually the case where other electrodes are employed.

The welding of cast iron should be done very intermittently. In some cases "skip" welding is used with a weld not over 3″ made at one time. Immediately after each bead is deposited it should be lightly peened, thoroughly cleaned and allowed to cool before next bead is applied. Care should be taken to keep the work clean and not allow it to get too hot. A good rule in reference to cast iron is "Keep the work clean and cold."

Welding with Chrome-Nickel Steel Electrode.—Some welding operators have found that with the use of a heavily coated metallic electrode having 18% chrome, 8% nickel and a low carbon (.07 max.) content a firmer bond of weld metal with cast iron can be made than when a mild steel electrode is used. Light peening, while the welding bead is still warm, also helps relieve the contracting strains.

Welding with Carbon Arc.—Iron castings may be welded by the use of a carbon arc with a cast iron filler rod. Proper manipulation of the arc and filler rod when welding in flat position on heavy castings will produce a fairly machinable weld. This is due to the slower cooling of the deposited and base metal; the carbon arc being played about the work can prevent rapid cooling. By this method of welding it is possible to float the oxide out of the molten metal. If this is done hard spots which would cause trouble in the machining operation are eliminated. The use of a dehydrated borax flux is sometimes used, as it enables the operator to float out some of the undesirable impurities.

The cast iron filler rod used with the carbon electrode is usually of far higher grade material than the base metal. Thus the tensile strength per square inch area of the weld metal will be higher than the tensile strength of the casting.

Welding with Cast Iron Electrode.—When welding cast iron by the metallic arc process with cast iron electrode, it is usually necessary to preheat the casting in order to receive the molten metal from the end of the rod as fast as it comes off. The rod in this case is always worked on the positive side of the circuit. Where the job is to be machined after the weld, this process is objectionable, as it permits too rapid cooling, giving a hard weld. This process is not generally used.

Welding with Non-Ferrous Electrode.—The use of non-ferrous material for the electrode in the arc welding of cast iron solves one of the metallurgical problems in connection with the process. As distinguished and contrasted with the use of steel rod, non-ferrous alloys do not harden appreciably when deposited in cast iron base metal, because the non-ferrous alloys do not absorb carbon from the casting. The welds so made are therefore machinable. However, the hardening of cast iron in the casting adjacent to the line of fusion, due to the quenching action of the mass of cold metal back of it, remains the same as in the case of welding with a steel electrode.

One of the non-ferrous electrodes widely used in the arc welding of cast iron is the shielded arc bronze type. This electrode provides a soft weld possessing good tensile strength. The procedure is much the same as given under Bronze, Page 338.

Another electrode of this non-ferrous type is a shielded arc nickel electrode. Because of its soft, machinable welds and light penetration, it is used extensively for correcting machining errors, filling up defects and repairing cast iron parts which must be drilled, tapped or machined. See Fig. 430.

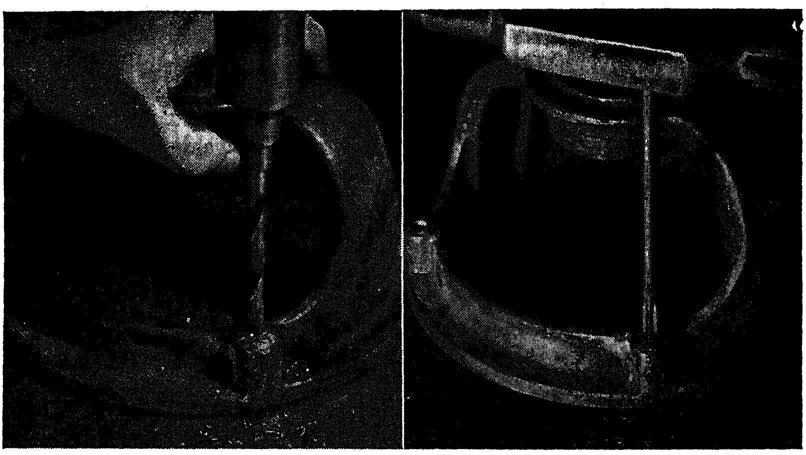


Fig. 430. This illustrates the machinability of cast iron welded with non-ferrous alloy electrodes designed for the correction of machining errors and other defects in cast iron. The weld deposit and fusion zone are exceptionally soft and can be drilled, tapped or cut readily.

Current should be just high enough to obtain satisfactory bond (70 to 130 amps.) and arc should be fairly long (approx. ⅛″). Weaving with short beads (2″ to 3″), followed by peening and cooling is recommended.

Where there is a large or deep area to be filled or where a strength weld is required, steel electrodes should be used to within approximately ⅛″ of the surface to be machined and then finished with several layers of this non-ferrous electrode.

Studding.—As explained previously, the chilling action of the cast iron increases the combined carbon and in turn increases the hardness and brittleness, weakening the strength of the cast iron just back of the line of fusion. Welds in cast iron, if of sufficient thickness, may be strengthened by the mechanical method of studding.

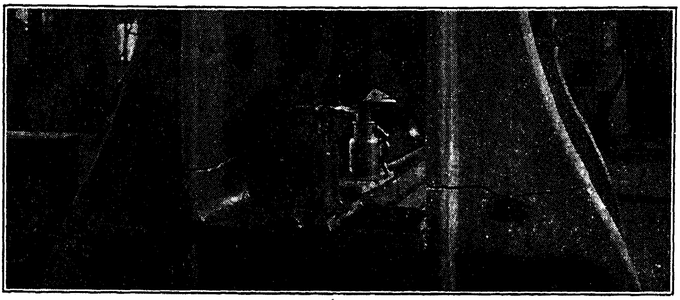


Fig. 431. Cracks in a cast iron end frame before preparation for welding.

Fig. 432. Cracks in cast iron end frame veed out, drilled and tapped for studs with some of the studs in place preparatory to welding.

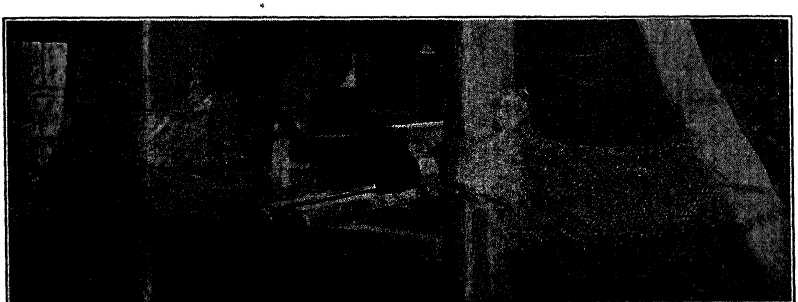


Fig. 433. Completed arc welded repair of cast iron end frame.

Studs of steel approximately 1/4″ to 3/8″ diameter should be used. The cast iron should be veed and drilled and tapped along the vee so that the studs may be screwed into the casting. The studs should project about 3/16″ to 1/4″ above the cast iron surface. The studs should be long enough to be screwed into the casting to a depth of at least the diameter of the studs.

The cracks in the cast iron end frame of a large bending brake, as shown in Fig. 431, present a typical application for repair by arc welding. Fig. 432 shows the cracks veed out, drilled and tapped for studs with some of the studs in place.

The cross sectional area of the studs should be about 25% to 35% of the area of the weld surface. In such cases the strength of the weld may safely and conservatively be taken as the strength of the studs. It is considered good practice to first weld one or two beads around each stud, making sure that fusion is obtained both with the stud and cast iron base metal.

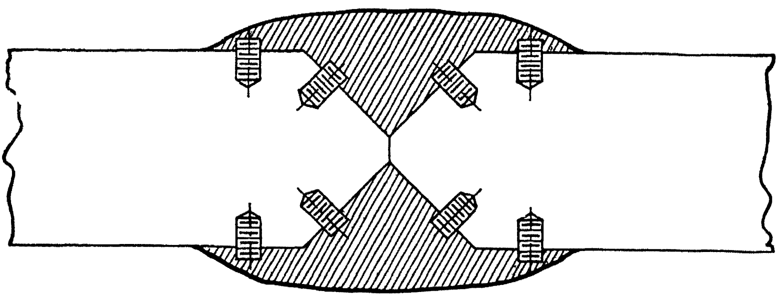


Fig. 434. Usual procedure of studding for cast iron welding.

Straight lines of weld metal should be avoided so far as possible. Welds should be deposited intermittently, and each bead peened before cooling. The completed welded repair of broken cast iron frame, as portrayed previously, is shown in Fig. 433.

It is advisable where the casting is of sufficient thickness to vee from both sides and stud, this should be done as indicated in Fig. 434. In many cases it may be desirable to produce complete penetration at the fracture.

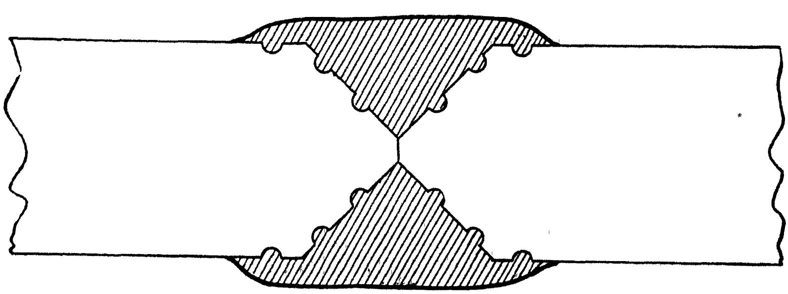


Fig. 435. Showing use of grooves instead of studs in welding cast iron.

In some cases it may be practical and more desirable to shape out grooves in the casting with a round-nosed tool instead of studding. This method of preparation is shown in Fig. 435.

Cast Steel

Cast steel in general has the same chemical constituents as ordinary steel, except it is poured into a mould in the shape wanted instead of billets and rolled as in the case of structural steel. As a result the welding practice for cast steel should generally be the same as for rolled steel.

Welding of steel castings may be divided into three general classes:

1. Welding cast steel to rolled steel in sub or main assemblies of machinery or equipment.
2. Welding of cast steel in the field as a repair or maintenance problem.
3. Welding cast steel in the steel foundry to remedy casting or foundry defects.

In items 1 and 2 the metallic arc is most generally used, with a mild steel electrode, the procedure being practically the same as for rolled steel.

Item 3 constitutes by far the largest amount of this type of welding.

Due to the characteristic shrinkage of steel from a molten state to a cold state and sometimes other troubles the following defects many times appear in the casting.

(a) Blow holes, sand holes and other skin imperfections.
(b) Shrinkage, cavities due to contraction of the steel, chiefly during solidification.
(c) Cracks formed by the contraction of the steel in the solid or semi-solid state.

One way of correcting any such defects is, of course, to scrap the casting and remelt and recast it, but this is a very expensive way and it is quite general practice to repair many such defects by arc welding. For this work it is quite common to use either metallic or carbon arc, depending upon the type of defect and the welding practice of the particular foundry where the work is being done.

Metallic arc welding is used for many cracks and blow holes, with a mild steel electrode following the usual procedure for steel. Care should be taken to chip and clean the crack or hole very carefully before starting the weld; as each layer is put on, it is desirable—although not always necessary—to peen. Each layer should be carefully brushed before starting the next. In larger work the speed of the carbon arc is desirable and it is very often used. Care should, however, be taken not to let the carbon electrode touch the molten metal so as to eliminate the absorption of carbon. This can be done when the arc is broken by starting or striking the arc on a cold part and then moving over to the welding point. The carbon arc method is also desirable since it can be used to cut or enlarge a blow hole for welding; also since by its use a larger area of metal is molten, slag, sand, etc., can be floated off to a good advantage.

The shielded arc process of welding can be used to excellent advantage in steel foundries in the repair of defects in steel castings. In the use of this process electrodes $\frac{5}{16}''$ and $\frac{3}{8}''$ in diameter can be used successfully, resulting in a deposition of 6 to 15 pounds or more of deposited weld metal per hour. Weld metal so deposited is soft and ductile but of high tensile strength. The heavy coating of the electrode used with the shielded arc process prevents grounding, permitting the operator to get at the bottom of holes and other places not of easy access.

Steel Castings Arc Welded to Rolled Steel. — Generally the castings are machine parts which are fabricated into an assembly of welded rolled steel construction. This application of welding has grown from the redesign of machinery from entirely cast construction to part cast, part welded, rolled steel construction, and is made possible by the ability to weld steel castings to rolled steel. This is easily accomplished, the welding procedure being practically the same as for welding rolled steel. See Fig. 475.

Malleable Iron

Malleable iron is white cast iron which has been heat treated so that the carbon content of the casting occurs in uniformly distributed particles called temper carbon. When this carbon is in this condition the castings are not nearly so brittle as gray cast iron. The result is that the casting will have physical properties between gray iron and steel castings. Its tensile strength is much higher and its ductility much better than gray iron. It is softer and may be bent to a certain degree.

When welding the carbon is still there but in a little different form, and when it is heated and cooled quickly the effect of the heat treatment or annealing is destroyed in the vicinity of the weld.

There are therefore generally the same problems as in the welding of gray cast iron and the same precautions and welding procedure should generally be followed.

In many malleable foundries it is common practice to weld small defects with the metallic arc process and then put the casting through the annealing oven, to overcome the change in structure due to welding. In the field this is generally impractical and impossible.

General instructions in arc welding malleable iron:

1. Use same procedure and caution as in welding gray iron.
2. Where practical put the casting through the annealing process, by which it was originally made. Where this is not practical, annealing as in ordinary welding practice will help the qualities of the weld.

Wrought Iron

Wrought iron is made from a pasty mass instead of from a liquid as in the case of steel. It is a low carbon iron which contains many elongated particles of iron silicate slag. Its claim to superiority over dead soft steel is that it has a fibrous structure, which perhaps increases its toughness and its resistance to breaking under bending or under a sudden blow or shock. It is also claimed that iron in this condition is more corrosion resistant than ordinary steel.

As seen above, wrought iron is simply a form of steel with a low carbon content (usually below .12%) and a small amount of slag. The usual procedure for welding steel should be followed. The carbon being low, there is no ill effect of sudden cooling. The metal added, however, by the bare or lightly coated electrode will not have the ductility of the wrought iron. However, the shielded arc process is usually employed and weld metal can be deposited having a high ductility and a tensile strength even greater than the wrought iron, and of high corrosion resistance.

Forgings

A forging is in effect a carbon steel which has been properly preheated and then hammered either by hand or by a steam hammer, into the proper shape for use. This mechanical treatment, like rolling, gives the forging certain desirable characteristics. In this way are made many automobile axles, connecting rods, crankshafts, gear blanks and many small parts which could not be rolled. A great many forgings are afterwards given heat treatments which impart to them required physical properties for various uses.

Forgings may be readily welded following the usual procedure for mild or low carbon steel, remembering that with the bare or washed electrodes the weld will not be as ductile or have the same characteristics as the original forging.

Use of the manual shielded arc process usually employed is advantageous in welding forgings, for with this process a weld high in ductility and strength is produced.

In case the forging has been heat treated, it must be remembered that welding will destroy the effect of the heat treating in the vicinity of the weld. However, when the shielded arc process is used the forging can be heat treated again and even reforged successfully.

Copper and Bronze

Copper is usually a very pure metal. It is a good conductor of heat and is tough, ductile and malleable.

Copper has two characteristics however, which from welding viewpoint are not so desirable. First, it absorbs gases such as carbon monoxide and hydrogen readily. These are released when the metal starts to solidify. When entrapped, porosity results.

Secondly, it oxidizes rapidly when undergoing fusion and the oxide is dissolved in the molten metal. It is possible for it to take up such large quantities that the mechanical characteristics of the weld metal would be very seriously affected.

Another characteristic which makes copper difficult to apply is that the tensile strength decreases very rapidly as the temperature increases. This is true from 500 degree F. and up. The result is that at 900 degree F. the tensile strength is approximately 40% of what it is under normal atmospheric conditions.

Copper has a high coefficient of contraction. Care should be taken that contractional movements during cooling of the weld are counteracted so that the weld metal or the metal adjacent to it will not fail due to low tensile at approximately 900° F.

Deoxidized Copper.—Copper containing small percentage of silicon, phosphorous or other deoxidizer is commonly designated as "deoxidized" copper to distinguish it from commercial or electrolytic copper. Presence of the deoxidizer inhibits the formation of cuprous oxide at the grain boundaries of the copper and thus makes feasible fusion strength of 30,000 to 35,000 lbs. per sq. in. Use of deoxidized copper filler rod is desirable, of course, to assure a weld having the characteristics of the deoxidized base metal.

Melting Temperature.—Copper melts at about 1980 deg. F. It has a rate of heat transfer approximately ten times higher than that of steel. The ratio of expansion and contraction is in the ratio of steel to copper of 63 to 93.

Preparation of the Joint.—First, the joint to be welded must be clean. If oxides exist it may be cleaned by using 10% sulphuric acid solution which has been warmed. Thickness up to 1/4" need not be beveled for welding but above that it is recommended in accordance with the same beveling as for steel joint (Page 41). Welding is greatly facilitated when the work is clamped to a backing of carbon or graphite blocks beneath the joint. If this is not practical then elevate the two sheets to be welded with pieces of metal about the thickness of a hack saw blade, the elevating pieces being placed so that the bottom of the joint and the work table have a space between them. This permits the deposit of a small amount of excess metal on the underside of the metal, sufficient so that when the weld is completed, the underside can be machined and still have the weld flush with the parent metal. See Fig. 436.

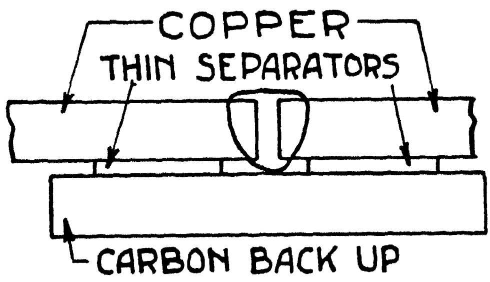


Fig. 436.

Welding.—Copper may be welded by the carbon arc process either manually or automatically, or by use of metallic shielded arc electrode. Where practical, the automatic carbon arc process is recommended for best results, namely a smooth, dense weld. However, the manual carbon arc produces very satisfactory results when a high capacity, high efficient arc welder capable of delivering uniform welding current is used. This type of arc welder is necessary to maintain the required voltage, which is from 35 to 50 volts, depending on thickness of plate.

The composition of the filler rod will vary according to the physical characteristics required of the welded structure. If the weld must have low electrical resistance, the filler metal may be of pure copper or cad-

mium copper. Where electrical or thermal conductivity are not essential but where only ductility and physical strength are required the filler metal may be of Everdur, Silicon copper, or suitable grade of phosphor bronze.

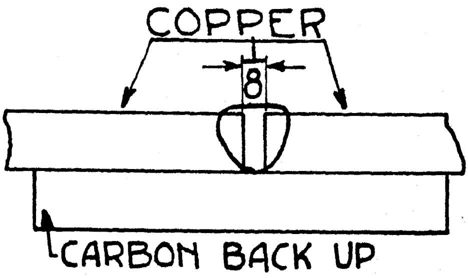


Fig. 437.

The manual process may be used by applying the proper size rod to the plates to be welded with a distance of about ⅛" between the plate edges to be welded. See Fig. 437. The rod is melted into the plate and fed in by hand as the weld progresses. The rod used would be about 20% heavier than the thickness of the metal being welded. The best results are obtained at high speed. A welded joint in copper produced in this manner is shown in Fig. 438.

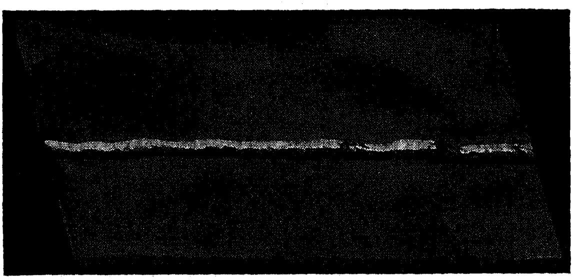


Fig. 438. Welded joint in copper produced by the manual carbon arc process.

Direct the arc on the filler rod.

It should be noted that, due to the high heat conductivity, when light currents are used, preheating is necessary. This can be done with the carbon arc 1" or more in length, and moved rapidly over the surface. It should also be noted that while cold rolled copper may have a strength of 55,000 lbs. per sq. in. that the strength of welded copper cannot be higher than annealed copper which is around 30,000 lbs. per sq. in.

The arc should be long. The distance between the carbon electrode and the work being such as to allow the carbon monoxide produced by the carbon arc to combine with oxygen and the atmosphere instead of entering into combination with the copper and forming an oxide with the resultant low physical characteristics as outlined above.

The weld should be made completely in one pass. The backing of carbon or graphite is recommended as being very helpful.

The results will vary with the quality of the copper, probably varying with the oxygen content. Best results will be had with deoxidized copper plates or sheets.

Steam—or moisture-producing fluxes must be kept away from the arc because of the readiness with which molten copper absorbs hydrogen.

It should be noted that there are two characteristics which must be observed. The first is that welding at high speed produces the best results. For example, better welds are produced at 20″ per minute on 1/4″ plate using 600 amperes at 40 volts, than will be obtained at 7″ per minute using 200 amperes. Second, voltage of the carbon arc must be high, that is, a long arc must be used.

Shielded Arc Welding of Copper and Bronze.—A shielded arc electrode of the Phosphor Bronze type is used. The coating shields the molten metal from the contaminating influence of the air and assists in the easy flow of the metal in the arc. The resulting deposit is homogeneous and of good tensile strength with the characteristics of true phosphor bronze.

Applications include: Building up and filling in bronze castings, welding of brass and copper, etc., welding of busbars, large contacts, etc., welding of impeller blades in many pumps and turbines, building up bronze valve seats, building up bearing surfaces of bronze on steel or cast iron, fabricating ornamental bronze and bronze doors, etc., building up various guides, etc., such as locomotive guides, etc. Many types of bronzes such as manganese bronze and aluminum bronze are exceedingly difficult to braze and may be welded satisfactorily by shielded arc electrodes.

Procedure.—Positive polarity should be used, i. e., electrode positive, work negative, with the following values:

Size	*Arc Voltage*	*Amperage*
1/8″	22 – 26	50 – 125
5/32″	24 – 28	70 – 170
3/16″	24 – 28	90 – 220

For best results the electrode should be held at approximately 90 degrees to the work.

On thin copper or bronze, it is generally unnecessary to preheat the metal. As the work progresses and the heat builds up, it may be necessary, in some cases to reduce the current.

On heavy copper and bronze, preheating may be necessary due to the high heat conductivity of these metals. This preheating usually can be accomplished most easily by using a carbon electrode with negative polarity and rapidly moving the arc over the area to be welded.

A fillet weld specimen in bronze, produced by an electrode of the above type is shown in Fig. 439.

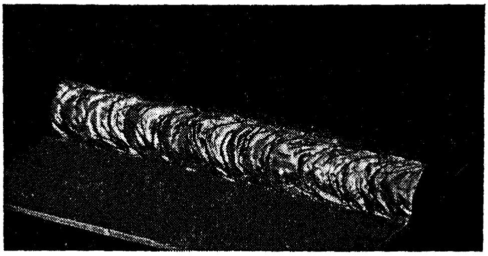


Fig. 439. Fillet weld in bronze produced with phosphor-bronze type shielded arc electrode.

It should be kept in mind that the characteristics of the base metal are of great importance in determining the characteristic of the joint and fusion zone. As an example if some lead is present and the base metal is melted into the welded joint then porosity will result — this being caused by the admixture of the base metal.

Therefore, since high current, high temperatures, or considerable penetration will cause a great admixture of the base metal, the first layer procedure should take this into account. If a metal of this type must be welded then the probabilities are that porosity will exist at the junctures of the bead with the base metal and of the beads or layers. It is therefore advisable to put on as much metal per bead, or layer, as practical.

Types of metals which evolve gases in the molten state, just about at the point of solidification, result in porosity. In some cases the use of higher current, keeping the work hot, will tend to reduce this porosity.

Holding the electrode at an angle so that the flame of the arc is directed back over the work will aid in permitting the gases to bubble through to the surface.

Where the work has to be machined it is, of course, necessary that the original, or base metal, be cut away so that when the deposit is made the line of machining will come through near the top of the deposit and not at the junction zone. The work must be laid out to obtain this result.

Everdur

Everdur, a copper-silicon-manganese alloy, can be easily welded by either the metallic or carbon arc.

When welding with metallic arc an electrode of the same composition as the base metal is generally used. The size of the electrode and the thickness of the work to be welded regulate the amount of heat required. Polarity of the welding current should be reversed. The edges of the joint to be welded must be clean and free from scale. A flux composed of 90% fused borax and 10% sodium fluoride is considered most satisfactory when welding with a metallic arc.

The procedure given for metallic arc welding of Everdur is also applicable in general to carbon arc welding, with the exception that a shorter arc is held with the carbon electrode and using straight polarity. Where additional filler metal is necessary it should be the same composition as the base metal.

An automatic carbon arc may be used for welding Everdur. No flux is necessary for this process because no metal passes through the arc in automatic carbon arc welding. The welds will have a tensile strength equal to the base metal and are usually machinable and have an exceptionally smooth finish. Whether welding with metallic or carbon arc the edges of the base metal should be free from scale, as scale prevents proper fusion.

Brass

Brass can be welded manually by use of a suitable electrode or automatically with the carbon arc. Some of the zinc content of the base metal will vaporize out during welding, so that the weld metal will not be of the same composition as the base metal. The electrode should be of the shielded arc type, the coating of which aids in causing the metal to flow easily in the arc. The electrode is usually phosphor bronze and results in a very smooth surface, so it may be applied to numerous jobs such as building up bearing brasses, slides, etc. The procedure is in general the same as outlined under Bronze.

Aluminum

Pure aluminum and various aluminum alloys in sheet, forged, extruded and cast forms can be welded with either a metallic or carbon arc. For metallic arc welding a heavily coated electrode of 5 per cent silicon aluminum alloy is frequently used. The electrode coating should be such that it will dissolve any aluminum oxide that may be formed during the welding process. The coating should also form a very fusible slag to cover the molten weld metal and protect it from oxidation while cooling. High melting rate on most aluminum electrodes necessitates rapid welding and sometimes makes it difficult to get sufficient heat into the work. To supply sufficient heat and eliminate a tendency towards porosity along the line of fusion, it may be necessary to preheat slightly.

For manual welding with a metallic arc the general procedures which follow will apply to most welding of aluminum. The typical applications given with outline of proper procedure are for general guidance. These procedures apply not only for welding aluminum of thickness specified but also serve as a guide for welding heavier sections. Any specific application should be studied carefully and the general procedure modified in accordance with quality of weld desired, the fit-up, and the rate of dissipation of heat into members to be joined.

The speeds given in these selected procedures or applications are actual welding time only with *no allowance for fatigue, cleaning, setting up, etc.*, as these items vary greatly in different shops. Therefore an opera-

tion factor should be used depending upon the time the arc is actually in operation. The data given are based on the use of a well-known special type electrode which is widely used for welding aluminum. The data and procedure may therefore vary when other electrodes are used.

It should be noted that the arc voltage given is the actual voltage across the arc while delivering the specified current. The currents designated are those used to obtain the stated speeds. Any variation in current from those given will affect the welding speeds. Also the amount of electrode per foot will vary greatly depending upon fit-up and other conditions, and the figures given are intended as a guide only.

For best results, the polarity of the welding current is generally reversed. The electrode is connected positive, the work negative. Direct current is recommended. The arc should be short with electrode coating almost touching the molten pool of metal; the electrode to be held approximately perpendicular to the work at all times. The arc should be so directed that both edges of the joint to be welded are properly and uniformly heated. Welding should advance at such a rate to make a uniform bead. Before starting a new electrode the slag should be removed mechanically from the crater of the weld and from approximately one inch of the weld back of the crater. To start a new electrode the arc should be struck in the crater of the bead, then quickly moved back along the completed weld for one-half inch, then the welding should proceed forward after the crater is completely remelted.

Final cleaning of the bead can be accomplished easily by first chipping off the excess slag, then soaking the weld in hot 3 per cent nitric acid solution or warm 10 per cent solution of sulphuric acid for a short time, finally rinsing weld with hot water.

Welding of aluminum in a vertical plane can be accomplished by proceeding either in a downward or upward direction. Either a straight line forward motion or a weaving motion may be used in advancing the arc. Overhead welding should be made with a number of straight beads. The same general instructions as given previously apply for both vertical and overhead welding. In tack welding the current can be increased approximately 50 per cent above that for continuous welding. The electrode should be manipulated in a rotary motion.

Butt Welds.—The work should be held in position by jigs and backed up by copper, as illustrated in Fig. 440. When butt welding plates $1/8''$ and thicker the copper backing should be slightly grooved beneath the joint to be welded.

Welding of butt joints in $3/16''$ plate and heavier should be done with two beads, as indicated in Figs. 443 and 444. No backing or clamping is required for welding joints in this manner.

The general procedure as given previously should be followed in making these types of welds.

Fig. 440.

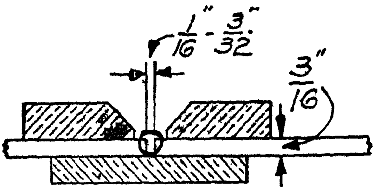


Fig. 441.

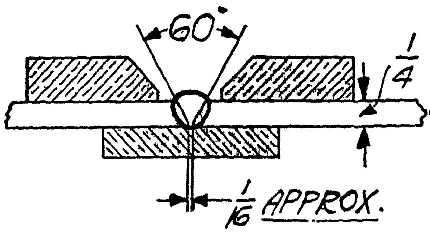


Fig. 442.

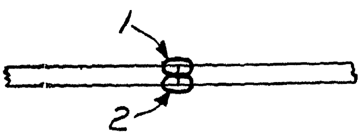


Fig. 443.

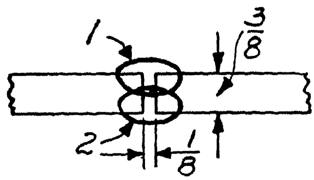


Fig. 444.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed Inches Per Min.	Arc Speed, Ft./Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 440 18 ga.	1	3/32"	40	20	22	110	.011
Fig. 440 14 ga.	1	1/8"	65	20	22	110	.0195
Fig. 440 1/8" plate	1	5/32"	120	20	16	80	.0537
Fig. 441 3/16" plate	1	3/16"	170	20	12	60	.100
Fig. 442 1/4" plate	1	1/4"	250	20	12	60	.140
Fig. 443 3/16" plate	1 2	3/16" 3/16"	170 170	20 20	17 17	42.5	.070 .070 .140
Fig. 443 1/4" plate	1 2	3/16" 3/16"	170 170	20 20	14 14	35	.086 .086 .172
Fig. 444 3/8" plate	1 2	1/4" 1/4"	250 250	20 20	12 12	30	.140 .140 .280

Fit up without gap may be used but the result will be a higher bead. With no gap on 3/8″ plate, 3/16″ rod and 225 amps. are used. For 1/2″ plate no gap butt joint, 1/4″ rod, 310 amps., 20 volts.

A butt weld specimen is shown in Fig. 445.

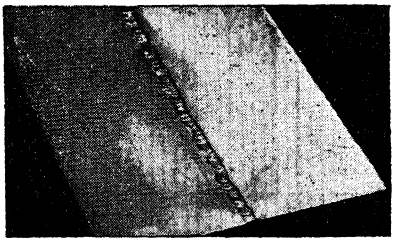


Fig. 445. Butt weld in 14 gauge aluminum.

Lap Welds.—This type of weld should be made in accordance with the general procedure outlined previously, except that the manipulation of the electrode should be in a small rotary motion, playing the arc first on the upper member of the joint and then on the lower member. The electrode should be held in such a position that the angle between the electrode and the horizontal plate is approximately 45°. Plate or sheets 1/8″ or less in thickness should be clamped in position for welding, as indicated in Fig. 446.

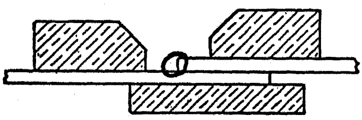


Fig. 446.

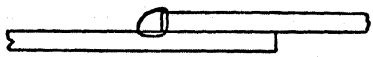


Fig. 447.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed Inches Per Min.	Arc Speed, Ft./Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 446 14 ga.	1	1/8″	65	20	13	65	.033
Fig. 446 1/8″ plate	1	5/32″	120	20	16	80	.0537
Fig. 447 3/16″ plate	1	3/16″	170	20	14	70	.086
Fig. 447 1/4″ plate	1	1/4″	250	20	14	70	.140

Fillet Welds.—In making fillet welds the electrode should be held in such a position that the angle between the electrode and the horizontal plate is approximately 45°. The electrode should be manipulated with a small rotary motion with the arc being played first on the vertical member and then on the horizontal member of the joint. With the above exceptions the general procedures given previously should be followed in making fillet welds.

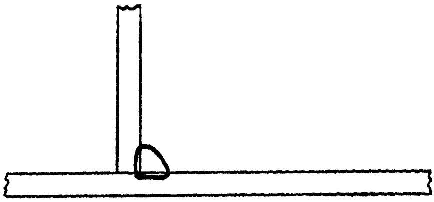


Fig. 448.

Joint	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed Inches Per Min.	Arc Speed, Ft./Hr.	Lbs. of Electrode Per Foot of Weld
Fig. 448 1/8" plate	1	5/32"	120	20	12	60	.0715
Fig. 448 3/16" plate	1	3/16"	170	20	10	50	.120
Fig. 448 1/4" plate	1	3/16"	170	20	9	45	.133

Edge Welds.—General instructions as given on Pages 340 to 341 apply for making this type of weld.

 Joint Fig. 449	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed Inches Per Min.	Arc Speed, Ft. Per Hr.	Lbs. of Electrode Per Foot of Weld
18 ga.	1	3/32"	40	20	28	140	.0086
14 ga.	1	1/8"	65	20	24	120	.0178
1/8" plate	1	5/32"	120	20	22	110	.039
3/16" plate	1*	3/16"	170	20	16	80	.075
1/4" plate	1*	1/4"	250	20	16	80	.11

*Weave this bead.

Corner Welds.—This type of weld is made by following the general procedure given on Pages 340 to 341.

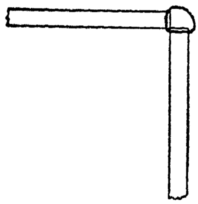


Fig. 450.

Joint Fig. 450	Beads or Passes	Electrode Size	Current Amps.	Min. Arc Volts	Arc Speed Inches Per Min.	Arc Speed, Ft./Hr.	Lbs. of Electrode Per Foot of Weld
1/16" plate	1	1/8"	65	20	24	120	.0178
1/8" plate	1	5/32"	120	20	22	110	.039
3/16" plate	1	3/16"	170	20	20	100	.060
1/4" plate	1	1/4"	250	20	20	100	.070

Monel Metal

Monel metal is an alloy of approximately 2/3 nickel and 1/3 copper, usually containing small amounts of tin, manganese, silicon and carbon rarely totaling more than 2%-4%.

Monel metal is regularly welded by all the processes commonly used with steel, including metallic arc and carbon arc.

The development of a heavily-flux-coated electrode of the shielded arc type has improved the arc welding characteristics of this metal. The miniature electric furnace effect resulting from the use of these thicker fluxes has resulted in welds of great ductility, strength and soundness, and, incidentally, good penetration with no under-cutting. The higher concentration of heat with the shielded arc type of Monel metal electrodes permits somewhat higher speeds and, consequently, less buckling.

The diameter of the shielded arc electrode should approximate the thickness of the sheet being welded, up to about 3/16". For plate heavier than that, either a 5/32" or 3/16" electrode can be used. Generally, if the electrode is held in position ahead of the arc—that is, if the electrode is "pulling" rather than "pushing" the arc—and the rod is held at any angle between 45° and vertical, very satisfactory results will be obtained. A uniformly short arc, as short as can be maintained without quenching, is to be preferred.

Reversed polarity, electrode positive, work negative, will be found most satisfactory when using the Monel metal electrode of the shielded arc type. A very uniform arc condition is obtained, resulting in a smooth uniform bead.

Determining the Correct Machine Setting.—The most convenient way of determining the best heat for a given job is to set the machine approximately and then proceed to weld. If the weld metal is not flowing out smoothly, the amperage should be raised, but if the weld metal is boiling, throwing off a shower of sparks and spattering generally, and the surface of the weld metal has a burnt appearance, then amperage should be lowered. It is difficult to make any but very general recommendations regarding machine settings because the following conditions surrounding a welding set-up seriously influence the setting of the machine: The machine itself; gauges of sheet being welded; whether welding single or multiple bead; whether joint is backed up with copper or being welded in the open; whether sheets are clamped to jigs or not, etc. All of these considerations are important and the operator must use his own best judgment in determining the machine setting which satisfies the conditions.

Setting Up and Welding Light-Gauge Sheets.—Seldom is the upper gauge limit for metallic arc welding of sheet metal of particular interest, but the question is rather how thin a gauge can be welded by this method. Ordinarily, .037″ (20 ga.) is considered the lower limit at which Monel metal can be conveniently welded by the metallic arc process. However, much welding by both carbon and metallic arc methods is being done in lighter gauges than this, but only through proper preparation of joint, judicious use of jigs, and experience. The use of $\frac{1}{16}$″ electrode with small welding machines permits welding of lighter gauges. For example, with a properly backed-up butt seam, held down tightly against the copper-backing bar, it is possible to arc weld 0.031″ Monel metal sheet by the metallic process, but this requires practice and a background of experience with these gauges.

Monel metal welds can be ground and polished on either or both sides, and these polished welds will be very clean and free of any porosity or slag inclusions. X-rays of Monel metal metallic arc welds on plate up to $\frac{1}{2}$″ thick attest to the soundness of these welds.

A transverse bend test is commonly used as a quick means of determining the ductility of the deposited metal. When applied to Monel metal, a complete 180° bend is obtained without sign of fracture, the pieces being hammered back to back.

Maintenance of a uniformly short arc is all important in the use of the Monel metal electrodes if maximum penetration and protection of weld metal are to be obtained. A slight slow weave across the seam is desirable to insure a more uniform penetration. On gauges ordinarily welded with one or two beads, there is no necessity for preheating, but where castings are to be repair-welded, it is desirable that these be warmed slightly before welding. After welding, the flux is easily removed by means of hand tools such as a chisel, handle end of file, etc. If any flux remains, it will not absorb moisture from the atmosphere, nor will it be corrosive to the parent metal.

Procedure for Using the Carbon Arc.—The carbon arc method of welding is being applied to Monel metal with no difficulty. It is, of course, necessary that the carbon pencil be negative (straight polarity) and that a suitable, coated welding rod be used. The Monel metal carbon arc welding rod is available for welding Monel metal. With the carbon arc

process, the carbon pencil is oscillated slowly across the seam and the coated filler rod dipped into the arc flame to melt off small drops of metal. This procedure of carbon arc welding is used rather widely on the gauges around .062″ and .050″ because of particular ease in working of uniform penetration.

Nickel

Nickel is regularly welded by all the processes common with steel.

For metallic arc welding a heavily-flux-coated electrode of shielded arc type results in excellent welding characteristics. The welds have high ductility, strength and soundness, with good penetration and no undercutting.

The procedure is essentially the same as outlined for Monel metal. A shielded arc electrode is used. The work is negative, electrode positive. The current is determined as indicated under the welding of Monel metal.

Welds in nickel, when ground, are clean and free from porosity. A transverse bend test shows slightly less ductility than Monel metal. A bend of 160° is the average deformation obtainable without cracking.

Nickel may be welded by the carbon arc process, the carbon being negative and the electrode being of suitable coated type. The carbon arc is used rather widely on sheets .062″ and .050″ thick because of the ease in working.

Nickel-Clad Steel

Nickel-clad steel is a ply material having a dense homogeneous sheet of pure nickel on a foundation of mild steel. The nickel cladding possesses the same chemical and physical properties as hot-rolled or hot-forged nickel in other forms. The cladding is firmly bonded to the steel base plate. The bond between the cladding and base plate provides the clad plate heat conductivity equal to that of solid steel or solid nickel plate. Maximum thermal efficiency is, therefore, obtained in all equipment requiring heat transfer through the wall. Thermal coefficients of expansion of the nickel and steel are nearly identical.

The choice of nickel-clad plate to meet particular corrosive conditions is governed by considering what may be expected of pure nickel.

Joints in nickel-clad steel are usually made by welding, the nickel side being welded with nickel welding rod to obtain a continuous nickel surface which protects the steel base from corrosion at the joint. Heavy steel plate is generally welded by the metallic arc process.

Where beveling is done by hand chipping, it is usually desirable to weld the steel side first to avoid the possibility of burning through, to prevent uneven welding, and other difficulties arising from variations in the separation of the joint and the thickness of the lip at the root of the bevel.

The skilled operator should have no difficulty in welding the nickel side. Operators inexperienced in the welding of nickel should study

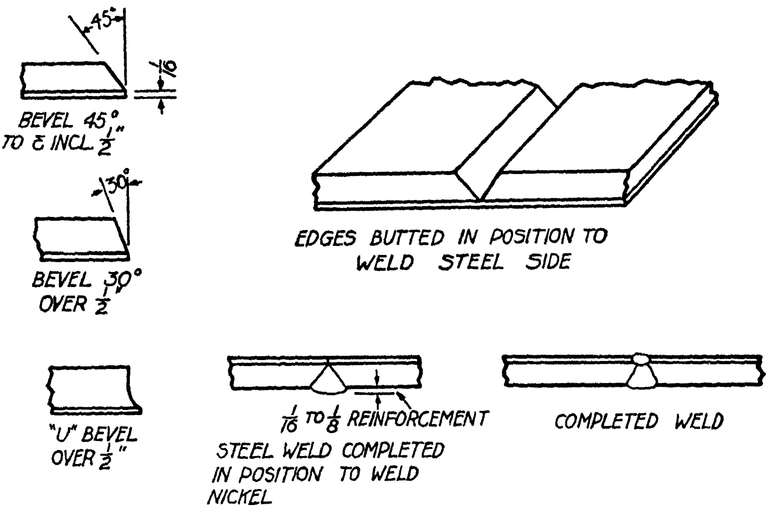


Fig. 451. Butt welded joint, metallic arc welded.

instructions on the welding of solid nickel plate, and then should make a sufficient number of test welds to enable the adjustment of their manipulation to suit the characteristics of nickel welding.

Principal points to be observed in the preparation of the joints, assembly and welding, include: (1) edges of the plate should be planed to give uniform alignment at the joint; (2) beveled butt joints should be assembled with the edges of the bevel at the lip closely butted; (3) joints should be welded first from the steel side, the nickel side should be cleaned free from icicles, slag, and heavy oxide. It is advisable to chip the seam with a round nose chisel to a depth necessary to expose sound metal at the root of the steel weld; (4) nickel metallic arc welding wire, for welding the nickel side. Electrodes may be procured in sizes 3/32″ to 3/16″ diameter by 18″ long; (5) operator should make trial welds with reversed polarity at several current values, and select the amperage that best suits the nature of the work and his own manipulative methods; (6) short arc, 1/16″ to 1/8″ long, is an absolute necessity; (7) selection of the size of electrode and the adjustment of the welding current must properly balance the penetration and rate of electrode fusion.

Various joints are used to meet the particular needs of the construction. The beveled butt joint, Fig. 451, should be employed whenever the nature of the work allows this type of joint. Field erection of large storage tanks may require the lap joint, Fig. 452.

For outside corner welds, it is preferable to use the methods shown at C and D, Fig. 453. Method A, Fig. 453, is not advisable due to large iron content of nickel weld metal in single bead. Multiple beads, as in B, Fig. 453, will show low iron content in the cover weld.

Points to observe in vertical welding of nickel-clad steel are illustrated diagrammatically in Fig. 454. Electrode size and current setting should be determined by careful trial. The welding is started with a deposit at the bottom of the seam to form an almost horizontal face or shelf. The

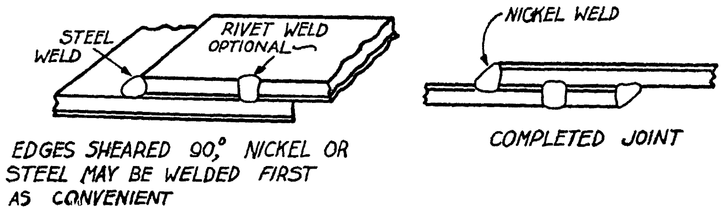


Fig. 452. Lap joint, welded with metallic arc.

electrode is inclined as shown in Fig. 454. Fusion at the base of the weld is kept slightly in advance of the outside. Peening is desirable to compact the nickel weld metal and enhances the weld density, strength, and appearance. In peening, flat-faced tools slightly rounded at the corners are used. The use of sharp-cornered tools, which might cut into the nickel along the line of the weld, must be avoided.

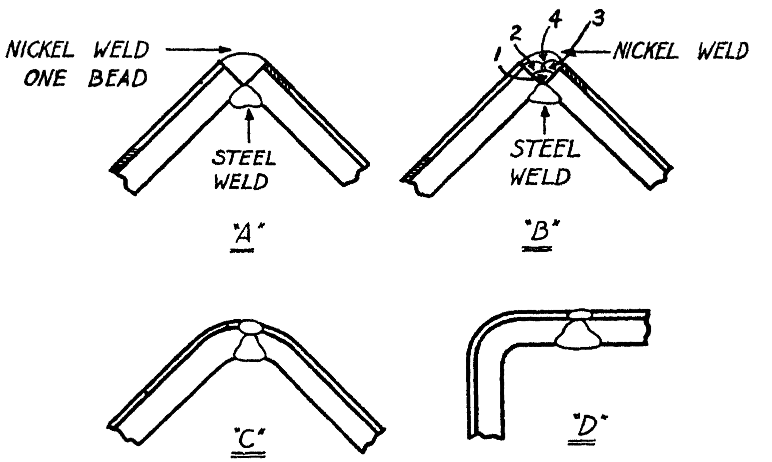


Fig. 453. Corner welds in nickel-clad steel.

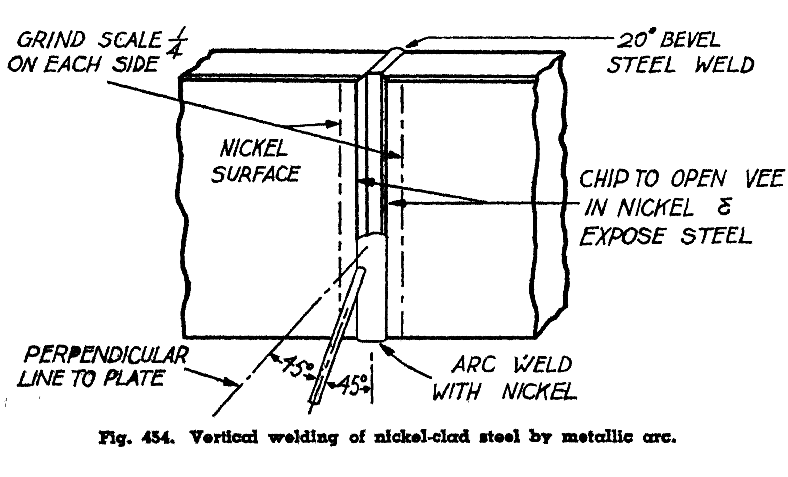


Fig. 454. Vertical welding of nickel-clad steel by metallic arc.

"Inconel," Nichrome and Similar Alloys

"Inconel" is an alloy composed principally of nickel combined with a much smaller percentage of chromium, resulting in a metal which is non-tarnishing. Approximate analysis is 80% nickel, 14% chromium and 6% iron.

It has excellent physical characteristics arc welded joints developing ultimate tensile strength of over 90,000 pounds per square inch and ductility of as much as 35% elongation in 2 inches. Inconel may be formed or otherwise shaped. Elongation and tensile strength do not vary greatly up to about 700° F. At that point these values decrease to a minimum at about 1400° F. This may be called "the hot short range." In the fabrication of parts these characteristics must be considered. It is available in the usual commercial forms—as sheet, plate, pipe, rods, etc. Since it is relatively expensive it is usually used in light sections or thin sheets, such as 18 gauge up to 1/8".

Inconel welds are rough-ground with coarse rubber-bond high speed grinding wheels. The finish then is gradually brought up by using finer grits of emery glued to sewn cloth wheels. Do not overheat metal. This grinding operation is accomplished rather easily.

A shielded-arc electrode is available for welding Inconel and other similar corrosion and heat-resisting alloys, containing from 70-80% nickel and from 11-15% chromium. Since these alloys are used largely in sheet form, small electrodes are usually used.

Polarity: Electrode positive and work negative. Hold a short arc. Use the following current:

Rod Size	Amperage Range	Arc Volts
3/32"	30–70	23–26

If more than one bead is used, clean the slag thoroughly from the preceding bead.

Thin sheets should be clamped against a copper or steel backing to maintain alignment of the seam and to make an easier welding job and to prevent the burning through of the base metal due to an improper fit up. In vertical and overhead welding, use the current on the lower side of the range.

Combinations of Various Metals

For maximum all-around economy, some applications require the welding of a combination of different metals. These combinations include: brass-to-steel — cast-iron-to-steel — high-manganese-to-low-carbon steel. Certain general conditions are to be considered in these cases.

The bead joining the two metals will be of composite make-up, due to the dilution or in-wash of one metal by the other.

This hybrid bead must be carefully considered as to its physical characteristics relative to the base metals. The heat effect of welding also affects the results. A third metal, deposited as a transition bead, may be used, and its effects are to be considered.

Brass-to-Steel.—Assume that it is required to join a brass bar to steel plate with a lap joint. A bronze electrode (see Page 338) is used. First, deposit bronze beads on the steel. These beads are then joined to the brass by the same type of bronze electrode. See Fig. 455. This same general procedure is followed in another case of cast-iron-to-steel.

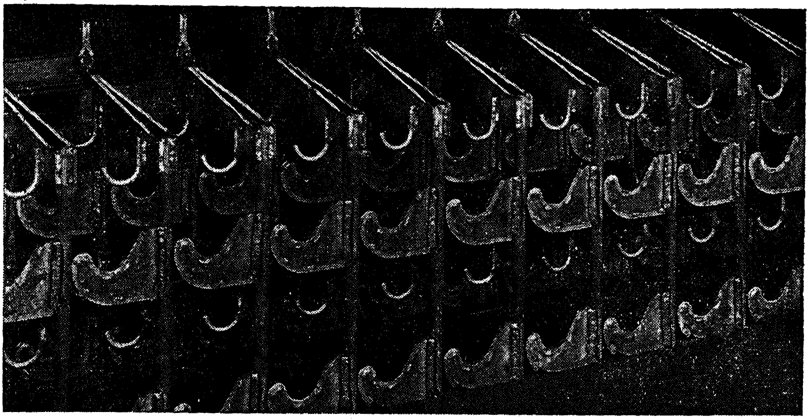


Fig. 455. Racks used to carry finished machined crankshafts and other motor parts. Brass bars are welded to steel to provide a rigid economical construction not injurious to machined parts which they hold.

Cast-Iron-to-Steel.—A suitable steel bead is placed on the cast iron. This may be of one or several layers. There are now in effect two steel surfaces which can be joined by the usual steel electrode. In some cases, where parts are not free to move or the cast iron is a bit difficult to weld, a special cast iron electrode (see Page 327) is used to deposit the bead on cast iron. This is then joined to the steel in the usual way as outlined above. In some cases the transition bead is an entirely different metal such as would be used in joining high manganese steel to low carbon steel.

High-Manganese-to-Low-Carbon Steel.—Due to the characteristics of manganese (see Page 320), an 18-8 stainless steel electrode (see Page 304) is used to deposit a bead on the manganese and this bead is in turn joined to the low-carbon steel by a stainless steel electrode. Or the stainless steel transition bead can be joined to the low carbon steel by a steel electrode.

These examples illustrate the use of transition or intermediate beads, and suggest that when two dissimilar metals are to be joined an electrode should be selected which may be easily and effectively deposited on one metal to form a surface which may then be joined readily to the other. Due regard for physical properties and heat effects upon these combinations of metals must be taken into account. Numerous problems are readily solved by this method of using transition beads.

Principles of Surfacing by Welding

Although surfacing by welding was used mostly for salvaging worn equipment in the early days of welding, the process is recommended and economically employed in applying effective wearing surfaces to new equipment during manufacture or prior to use.

The application of surfacing by welding should be considered from the viewpoint of service life of the equipment. Any piece of equipment must perform satisfactorily and meet certain very definite load conditions. Service life, measured in performance and cost of that performance, must be adequate. This adequate performance may be obtained either by making the entire part of a given kind of metal, such as steel, or by using one metal as a support and another to receive the load.

Four definite reasons for the use of surfacing in the fabrication of various types of equipment are: (1) It improves service life; (2) It reduces overall cost; (3) It lessens operating cost; and (4) Dimensions are maintained within fairly narrow limits when surfacing is used as compared to a single metal. The service life of equipment involves the load conditions to which the parts are subjected. These loads may be classified as to rate of application of the loading such as uniform, impact, and vibrating. Other factors affecting service life include wearing conditions, such as abrasion or corrosion and conditions of temperature. Under impact loading, the time rate of application of the load is important. The impact effect of a slow-moving train on the rails as it traverses a cross-over is very much lower than that of a train traveling at high speed. In another instance, impact may be momentary as in the case of a shovel tooth striking a rock, or a cam operating in a machine. In considering wear, abrasion is usually regarded as a grinding action as when operating in sand; or a sliding, rubbing, or rolling action as when one metal moves over another. Corrosion involves gas or atmospheric conditions as well as liquids and, in some cases, the action of solids on the material under consideration. Operating temperatures also affect service life.

Insofar as surfaces deposited by arc welding are concerned, another consideration is important. This is the condition of the surfacing metal immediately after it is deposited. The surface either possesses its complete characteristics as deposited, or it must receive some subsequent treatment. For example, one surface may be hard as deposited, while another may require peening to obtain the desired hardness; or, in another case, the surface may require heat treatment after deposition. Thus, surfaces may be classified under two groups, viz: (1) load conditions and (2) condition of the surface after deposit, the latter being a factor in considering load requirements.

Electrodes are available for the deposition of different types of surfaces, each having its own characteristic. These electrodes may be grouped according to the ability of their deposits to resist:

1. Impact; which may be light or heavy in force, or may tend to deform the surface of the metal or cause cracking or chipping.
2. Abrasion; which may be either a grinding action due to contact of metal with sand, gravel and similar abrasive materials; or a sliding, rolling or rubbing action of one metal against another.

3. Impact and abrasion in combination; with one moderate, the other severe or both moderate or severe.
4. Corrosion; including actions of various chemicals, water and also oxidation or scaling at elevated temperatures. May be gaseous or liquid, or gaseous and liquid in combination.
5. Temperature; which may exist in conjunction with each of the above conditions.

Electrodes may be used to obtain surfaces of fairly high carbon steel. The exact hardness depends upon the rate of cooling and, to a lesser degree, upon the carbon content of the supporting metal on straight carbon steel. With natural cooling, hardness may be 20 to 45 Rockwell C. Peening increases hardness, for example, from 33 to 40 Rockwell C. Quenching in cold water at 1450°F. increases hardness to 50 Rockwell C.

Where shock and abrasion are factors, deposits may be air hardening alloy steel. Hardness of the deposits ranges between 40 and 45 Rockwell C. Depending on carbon content of the supporting metal, hardness may run as high as 52-55 Rockwell C. Parts of equipment subject to sliding, abrasive action, batter or repeated pounding and impact may be surfaced effectively with this type of deposit.

Where the surface is subject to sliding actions, and the parts must retain their dimensions under high temperatures—as, for instance, in metal cutting—a deposit equivalent to high-speed tool steel may be obtained. Such deposits, in original condition, will have hardness of 50-55 Rockwell C., provided it is not diluted too much by the supporting metal. When this dilution is kept to a minimum, as by using 2 beads, hardness may be as high as 60-62 Rockwell C. The surfacing metal retains its characteristic at rather high temperatures, approximately 1000° F.

Where an abrasive scouring action but very little, if any, battering or impact is encountered, as on agricultural implements, an abrasion resisting self-hardening alloy may be used to excellent advantage. Moderate peening increases the hardness from approximately 20-30 Rockwell C., to approximately 50 Rockwell C. The deposit retains its toughness with maximum hardness at the surface which is cold worked. The deposit may be hot forged.

When the type of deposit required to meet a given service condition is known, the selection of a suitable electrode is readily made. The table on Page 356 describes six different conditions very frequently met with in hard facing and the qualities of deposits from six well known electrodes which meet the conditions.

As an example of the use of surfacing to meet service conditions, take a cutter such as shown in Fig. 456 which is used for cutting rather

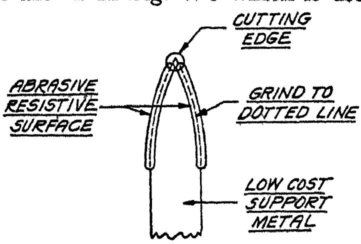


Fig. 456. Hard-faced cutter.

fibrous material under vegetable-acid conditions. The edge must cut, the sides must resist abrasion and all parts must be corrosion-resistant. Using a single metal to meet all requirements would obviously result in a compromise. By use of surfacing, however, the edge may be hard tool steel, and the sides an abrasion-resisting surface and the whole tool resistant to corrosion.

Another example is a cam as shown in Fig. 457. Here impact and sliding are the service conditions. At the point of impact, an impact-

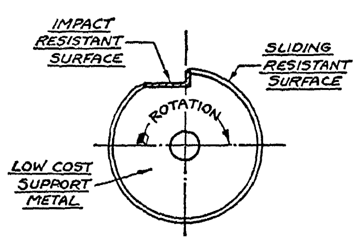


Fig. 457. Hard-faced cam.

resistant bead is placed, and at the point of application of sliding, a sliding-resistant bead is placed. Both are supported by a low cost base metal.

Surfacing applications such as these give the machine designer a freedom that permits him to meet the service requirements accurately. Moreover, the original dimensions can be maintained within reasonably narrow limits.

Surfacing by welding is very economical in a great many instances. Usually the surfacing metal which is rather expensive, is placed on a metal of rather low cost. The expensive metal need not be used except where it is in direct contact with the loading. Therefore, the total cost of the equipment including surfacing need never exceed the cost of the original equipment of single-metal construction.

For example, assume a single metal part of weight (W) which costs z cents per pound. A new design is desired, taking advantage of the economy of surfacing. We will assume that the proper surfacing material has been selected. The new part is to be made of metal of weight W^1 costing y¢ and surfacing metal w costing x¢ per pound. The problem becomes one of calculating the maximum permissible cost for the new design, assuming that the old one is efficient.

How Cost of Surfacing Is Calculated.—The maximum permissible cost for new design, assuming old design is efficient is the cost of the

less expensive metal plus the higher-cost surfacing metal or $xw+yW^1$. This must not exceed Wz, the original cost. The calculation for cost follows:—

$$xw + yW^1 = zW$$

Since

$$W = w + W^1$$

$$xw + yW^1 = zw + zW^1$$

$$xw - zw = zW^1 - yW^1$$

$$(x - z)\ w = (z - y)\ W^1$$

$$\frac{(x - z)}{(z - y)}\ w = W^1$$

Add w to both sides

$$\frac{(x - z)}{(z - y)}\ w + w = W^1 + w = W$$

$$\frac{(x - z + z - y)}{(z - y)}\ w = W$$

$$\frac{(x - y)}{(z - y)}\ w = W$$

$$w = \frac{(z - y)}{(x - y)}\ W$$

As an example, the maximum weight of surface metal at \$2.00 (z) per lb., with the supporting metal (y) at 5¢ per lb., and the cost of original design, using single-metal construction at \$0.80, is:—

$$\frac{80 - 5}{200 - 5} = \frac{75}{195} = 38.5\%$$

The calculation shows that the surface material may be as high at 38.5% of the total weight without exceeding the original cost. This clearly indicates the possibility of cost reduction as 38.5% is an extremely

Cost ¢/lb. Using Single Metal	Percentage of Total Weight Which May Be Surface Material Without Exceeding Cost of Using One Metal Throughout — Cost of Surfacing Materials: \$1/lb.	\$2/lb.	\$3/lb.	\$4/lb.	\$5/lb.
Cents	%	%	%	%	%
20	15.8	7.7	5.1	3.8	3.0
40	37.0	18.0	11.9	8.9	7.1
60	58.0	28.2	18.6	13.9	11.1
80	79.0	38.5	25.4	19.0	15.1
100	100.0	48.7	32.2	24.0	19.2
120		59.0	39.0	29.1	23.2
140		69.2	45.7	34.2	27.3

HARDNESS OF DEPOSIT (ROCKWELL)*

Type of Deposit	Electrode Application	Single Layer		Multiple Layer		Resistance to Corrosion	Heat Treatment
		As Deposited	Work Hardened	As Deposited	Work Hardened		
Medium Carbon Steel	Dense, tough surface to resist wear and deformation	25 C	30 C	28 C	32 C	Average	Same as for straight carbon steel
High Carbon Steel	Dense, tough surface of moderate hardness to resist shock and abrasion	30 C	35 C	35 C	40 C	Poor	Same as for straight carbon steel
Medium Carbon Alloy Steel	Resist wear due to rolling or sliding friction under high pressures	40 C	43 C	50 C	50 C	Fair	Air hardening
High Speed Steel	Cutting edges Metallic friction	58 C	58 C	62 C	62 C	Fair	Like high speed steel
Chromium Base Alloy	Resist abrasion and corrosion	50 C	50 C	54 C	54 C	Excellent	Self-hardening
Semi-Austenitic High Carbon Alloy Steel	Resist impact and severe abrasion	45 C	60 C	27 C	55 C	Good	No heat treatment Self hardening on cold working
High Mn.-Nickel Moly Steel	Resist severe impact and abrasion	93 B**	50 C**	93 B	50 C	Fair	Like high Mn. steel
Stainless Steel	Resist corrosion, severe impact and abrasion	35 C	48 C	85 B	42 C	Excellent	Like stainless steel

REMARKS: Values given are average obtained under laboratory conditions. Results will depend on such variables as current, mass of parent metal, size of bead, rate of cooling, etc. In most cases no heat treatment is necessary or desirable. Notes on heat treatment are only to identify the type of deposit and provide a guide in case of an unusual application where some heat treatment is used. It should be understood that these hardness values are with no heat treatments.

*On mild steel. **Manganese steel.

high percentage for the amount of surfacing on any part. It is obvious that any reduction in this weight is very profitable. In this particular case, it is at the ratio of 200 to 5 or 40 to 1. Percentages of metals which may be surfaced without exceeding original cost are given in the accompanying table.

The table indicates that for a surface material as high in cost as \$5.00 per pound against an original cost of 20¢ per pound, 3% may be surfaced by welding and the original cost not exceeded. More usually it will be found that 20% or more may be surface metal without exceeding the original cost. This indicates the great cost reduction possible by using surfaces of high grade metal against surfaces of baser metal.

Percentages of metals which may be surfaced are also shown in curve form in Fig. 458. Knowing the cost per lb. of surface material, and the cost per lb. of the part when made of a single metal, the % of total weight of the surfacing material which will give a cost not to exceed the original cost is easily determined. Any percentage below those given is very profitable. It should be noted that too much or too deep surfacing may be undesirable. Not only is it costly, but it may be found that the metal may not be as satisfactory as when deposited in fewer layers. Proper design utilizing hard facing surfaces requires just the proper amount of surfacing material. Hard facing, properly used, will permit a lower cost than if the part were made entirely of one metal. It will also provide improved service life because the surface most applicable to the

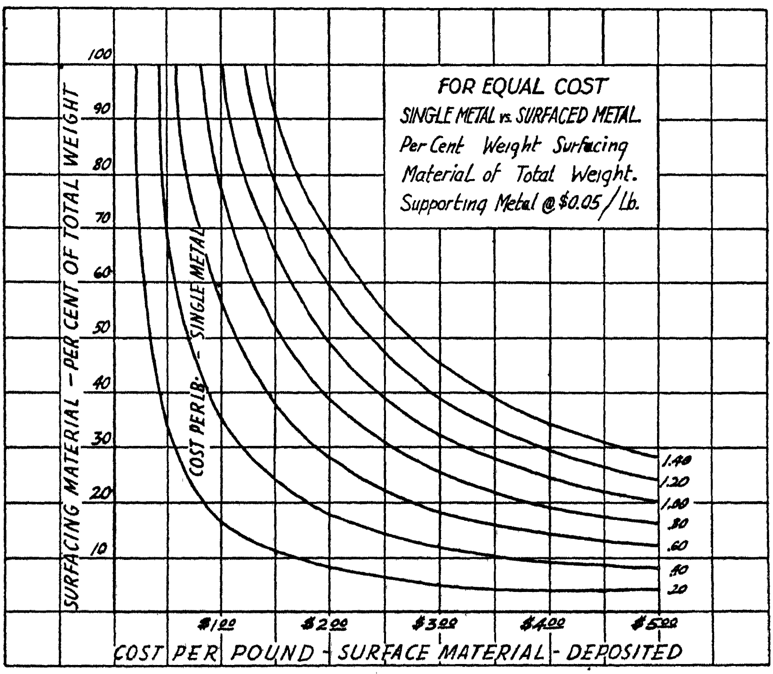


Fig. 458. % of total weight which may be surface material without exceeding cost of using one metal throughout.

design may be used without any great reference to the rest of the machine or equipment. A reduction in operation cost will also be provided because of the superior wearing qualities of the surfacing metal. It is, therefore, easily seen that design worked out by selecting the surface to meet the load or service requirements will result in superior service life at lower costs.

The hardness of the deposits given in the preceding table is designated by Rockwell values. The following conversion table gives the equivalent Brinell values.

Brinell	Rockwell C	Rockwell B	Brinell	Rockwell C	Rockwell B	Brinell	Rockwell C	Rockwell B
780	70		401	42	*113*	235	22	99
745	68		388	41	*112*	229	21	98
712	66		375	40	*112*	223	20	97
682	64		363	38	*110*	217	*18*	96
653	62		352	37	*110*	212	*17*	96
627	60		341	36	*109*	207	*16*	95
601	58		331	35	*109*	202	*15*	94
578	57		321	34	*108*	197	*13*	93
555	55	*120*	311	33	*108*	192	*12*	92
534	53	*119*	302	32	*107*	187	*10*	91
514	52	*119*	293	31	*106*	183	*9*	90
495	50	*117*	285	30	*105*	179	*8*	89
477	49	*117*	277	29	104	174	*7*	88
461	47	*116*	269	28	104	170	*6*	87
444	46	*115*	262	26	103	166	*4*	86
429	45	*115*	255	25	102	163	*3*	85
415	44	*114*	248	24	102	159	*2*	84
			241	23	100			

Figures in italics are an approximation and are to be used only as a guide.

Procedure for Obtaining High Carbon Steel Facing.—This procedure is given for use with a lightly coated electrode which deposits a high carbon (approx. 1.0%) steel facing. In welding with this electrode the electrode should be positive, the work negative. Wide or narrow beads can be deposited as desired. Each bead should be brushed thoroughly before depositing the next. Peening the completed bead will harden the deposit somewhat. Quenching in cold water will also increase the surface hardness. The deposit cannot be machined unless cooled very slowly or annealed. When shaping is necessary the facing should be ground. The hardness of the deposit depends upon the rate of cooling and upon the carbon content of the steel being built up. For best results the work should be in as near flat position as possible. However, where vertical welding is unavoidable, the welding should start at the bottom and proceed upward. Overhead welding is not recommended. The following tables give the proper current to be used for the various sizes of electrode when welding in flat and vertical positions.

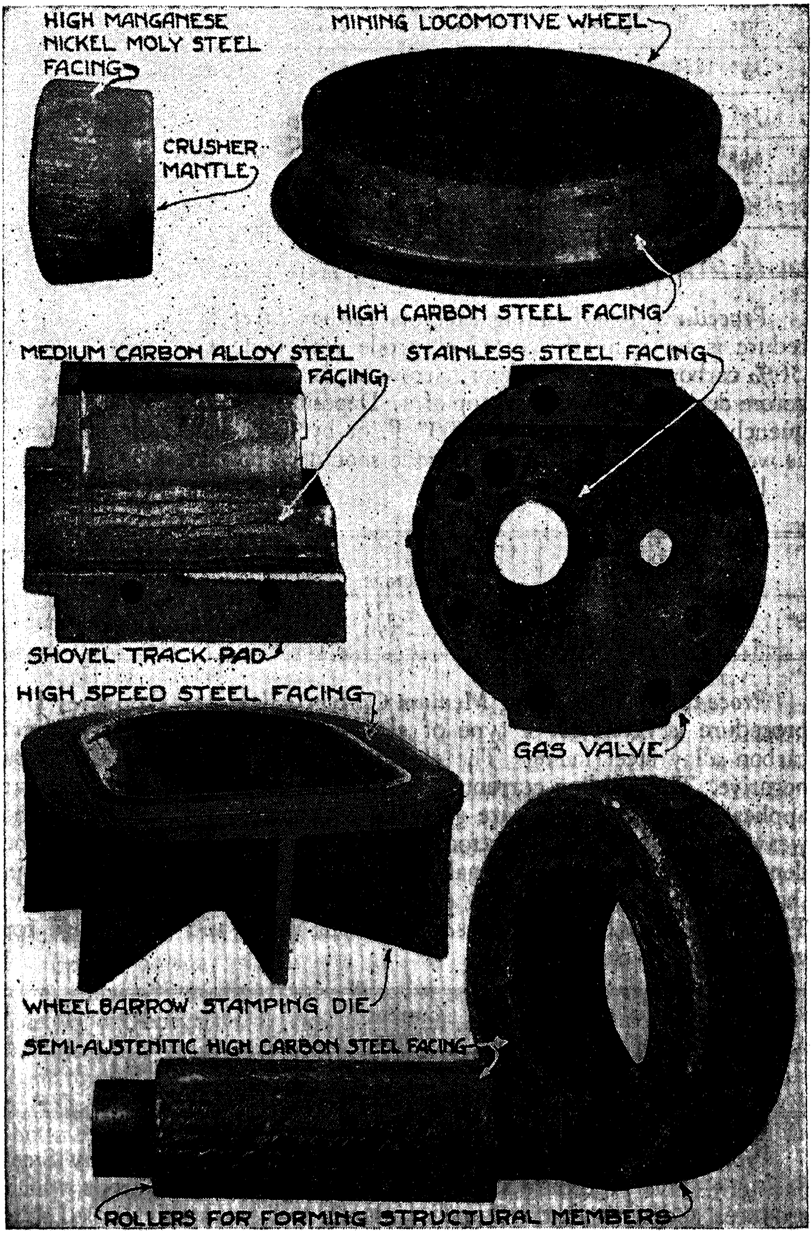


Fig. 459. Group of parts hard-faced by arc welding.

Flat			Vertical		
Rod Size	Current Range	Arc Volts	Rod Size	Current Range	Arc Volts
3/32"	25- 70	18-22	3/32"	25- 70	18
1/8"	70-110	18-22	1/8"	70-120	18
5/32"	100-150	20-25	5/32"	125-150	20
3/16"	150-225	20-25	3/16"	150-180	22
1/4"	225-350	20-25			

Procedure for Obtaining Medium Carbon Steel Facing.—This procedure is for a lightly coated electrode with deposit of approximately .50% carbon. Deposit wide or narrow beads as desired. Brush each bead before depositing another on top of it. Deposit may be hardened by water quench from approximately 1500° F. or by flame hardening. Surfaces as welded, are machinable. Electrode should be positive, work negative. Use following current ranges:

Electrode Size	Amperage	Arc Voltage
3/16"	150 – 225	20 – 25
1/4"	200 – 350	20 – 25

Procedure for Obtaining Medium Carbon Alloy Steel Facing.—This procedure is given for a type of electrode which deposits a medium carbon alloy steel facing. The electrode should be positive, the work negative. The welding current should be adjusted to suit the particular application. Flatter beads are generally produced at high currents. The weaving motion of the electrode should be used where possible. The deposited metal is not machinable and must be ground to shape when shaping is necessary. Welding should be done in the flat position only. The following tabulation gives the current range and arc voltage for various sizes of electrodes.

Rod Size	Current Range	Arc Volts
3/16"	110-275	28-34
1/4"	150-400	30-36

Procedure for Obtaining Semi-austenitic High Carbon Alloy Steel Facing.—This procedure is intended for use with an electrode which produces a deposit that is largely austenitic when rapidly cooled, but which transforms largely to martensite on slower cooling or on cold working, thus increasing its hardness and resistance to abrasion. It is commonly known as the self-hardening type of facing. Polarity of the electrode should be positive, the work negative. In general thick multi-layer deposits should be avoided. When facing straight carbon steel or

low alloy steel the facing should be built up largely with a high carbon steel deposit and overlaid with about two layers of semi-austenitic high carbon alloy steel as produced by this particular type of electrode. When the application requires a thicker deposit a layer of 18-8 stainless steel should be applied first, and then the first deposit should be overlaid with semi-austenitic high carbon alloy steel to the required thickness. Each layer should be peened after depositing. In hard facing high manganese steel, the facing may be built up partially by use of an electrode depositing a high manganese-nickel-molybdenum steel, or a semi-austenitic high carbon alloy steel deposit may be used entirely. In either case, each bead should be peened after depositing to relieve cooling stresses.

Deposits of semi-austenitic high carbon alloy steel must be ground to shape, as they cannot be filed or machined. When welding, the best results are obtained by weaving beads about 3/4" wide. The following current values and arc voltages should be used.

Rod Size	Current Range	Arc Volts
5/32"	100-165	22-25
3/16"	125-200	24-27
1/4"	175-230	26-32

Using Alloyed Powder for Hard-Surfacing.—Many alloyed electrodes are available for hard-surfacing, but for some purposes, particularly for a thin surfacing, powder alloy is frequently used and such a fine-grained alloyed powder is available for application with the carbon arc to produce a super-abrasion deposit as thin as .025 inch. When properly applied will give a coating with a hardness of approximately Rockwell 54C. This hardness will vary somewhat depending upon the amount of admixture with the base metal to which it is applied. This alloy develops its full hardness in the as-deposited condition, maintains its hardness at high temperatures and resists scaling at high temperatures. The deposit cannot be softened by annealing. Corrosion resistance will compare favorably with that of Stainless Steel. Its resistance to abrasion is excellent but should not be used where impact is excessive.

Spread powder evenly over area to be surfaced and to a depth of 2 to 3 times the desired thickness of deposit. Use a sharp, well tapered carbon with negative (normal) polarity and fuse down with a weaving motion. The exact heat required depends on size of work. Use enough heat to obtain a free-flowing puddle but not enough to dig into the base metal. Whenever possible weave the full width of desired deposit and build to desired depth in one pass. If more than one pass is required the work must be kept hot. Avoid heavy deposits.

Procedure for Depositing High Speed Tool Steel.—The following procedure should be used when welding with an electrode which deposits this type of metal. The polarity of the electrode should be positive, the work negative. Where only one bead can be used, currents should be low to keep down the admixture of base metal with the weld metal. Beads should be laid with a weaving motion to insure minimum porosity. On vertical surfaces the best results are obtained when welding is started

from the bottom and proceeded upward. After each bead is deposited it should be thoroughly cleaned before welding the next bead. The following current values and arc voltages may be used as a guide when welding in flat position. The exact values depend upon the mass of the parts being surfaced and the desired thickness and hardness of facing.

Rod Size	Current Range	Arc Volts
3/32"	30- 65	21-25
1/8"	65-100	22-26
5/32"	90-160	23-27
3/16"	125-200	25-29
1/4"	175-275	25-31

The following suggestions will prove helpful in obtaining best results in depositing high-speed tool steel: (1) Avoid welding on a cold piece of hardened steel, or on deposited metal which has become cold. Always preheat to 200°-400° F. and do not allow the part to cool below 200° F. if additional metal is to be applied. (2) Do not overheat the deposited metal during welding to the point where it shows red heat for more than a few seconds after the arc is broken. This can be controlled by balancing the electrode size and current against the mass and temperature of the part being welded. (3) Wherever possible, weave beads the full width of the surface to be built up. This promotes uniformity in hardness and less tendency to cracking. (4) After a layer has been deposited, allow it to cool — preferably in still air — to approximately 200°-400° F. If for any reason, welding must be stopped between beads and the deposit is allowed to cool below 200° F. always preheat before resumption of welding. (5) Clean up the surface of the deposit well before applying another layer. Touching the surface to a grinding wheel to even it up is very helpful. (6) Avoid piling up a thick deposit of metal. Two or three layers are nearly always sufficient.

In making cutting tools by depositing high speed steel on low or medium carbon base metal, the following suggestions, in addition to those previously mentioned, will aid in obtaining best results: (1) If there is a choice of base metal, use hot-rolled steel rather than cold-rolled since the latter may cause porosity due in some cases to high sulphur content. (2) In general, the minimum size tool bit which can be made up economically by application of high speed steel by arc welding will be determined by the size of the tool, the manner in which it is to be used and the frequency of its use. The tool can be ground and refaced and the original size retained indefinitely. Small size tools, special tools, or tools of odd or intricate shape, can often be made economically. (3) If maximum hardness and toughness are desired, reheat the completed tool to 1000° F., maintain that temperature for approximately two hours for every inch of thickness and cool in still air. (4) If the cutting edge must be finished to certain dimensions, a shelf built up with a mild-steel shielded arc type electrode at the edge of the deposit will eliminate considerable grinding. (See Fig. 460).

A cutting tool is made by taking a piece of steel of proper analysis

and size, grinding the edge and face to the required depth and distance from the cutting edge, then depositing weld metal in accordance with the above procedure. After the cutting edge has been built up in the manner outlined, the deposit is ground to suit requirements.

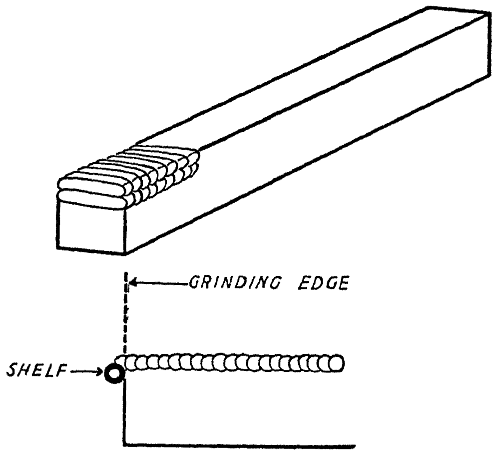


Fig. 460. Diagrammatic sketch illustrating how tool is made by arc welding.

Procedure for Obtaining Stainless Steel Deposit. — Procedure is given on Page 304.

Procedure for Depositing High Manganese-Nickel-Molybdenum Steel. — Procedure is given on Page 320.

Note: It is important, in the writing of welding specifications, that they should cover all of the requirements of the particular job. However, there are numerous jobs where very simple specifications will suffice. Elaborate specifications should be used only where absolutely necessary inasmuch as they tend to increase welding costs.

FLAME-HARDENING

Flame-hardening is a process in which the temperature of the surface of a quench-hardening ferrous material is rapidly raised by means of the oxy-acetylene flame to a point above the critical, and then quenched. This produces a wear-resisting surface which can be varied, as desired, in degree and depth of hardness.

Flame-hardening possesses distinct advantages over other hardening methods. From an economic standpoint, two of these advantages are speed and portability. This process permits the hardening of any accessible portion of an article at progressive speeds of from 3 to 10 in. per min., depending on the depth of case desired in contrast to the slower methods used in furnace-hardening and in such processes wherein the chemical composition of the material is changed as carburizing, cyaniding, or nitriding. No furnaces are required and the tools of the process can be taken to the work.

There are also advantages in the adaptability of the process for con-

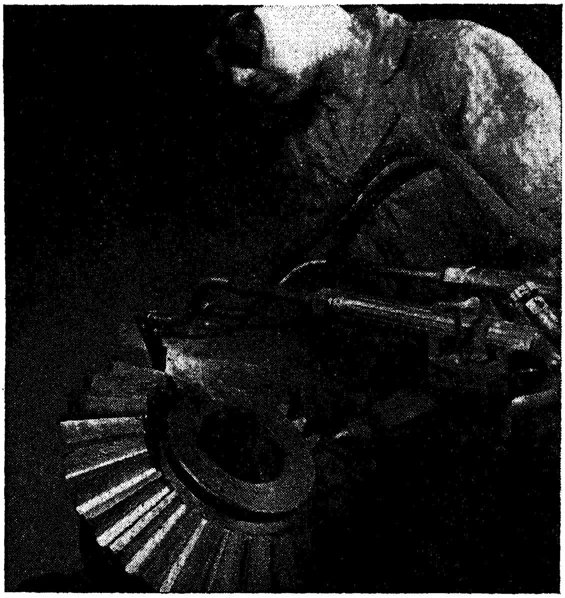


Fig. 481. Typical application of flame-hardening.

forming to local conditions and for achieving the desired results. The localized heating of flame-hardening permits hardening large or irregular surfaces, and also helps to minimize distortion. Likewise, the surface of a part can be hardened without disturbing its core, whereas in furnace-hardening the part is heated throughout. Thus with flame-hardening it is possible to heat-treat the core of a part to obtain such desired properties as toughness and ductility, and then to flame-harden the wearing surfaces to the desired hardness while still retaining the core properties.

Materials.—In general, any steel that can be hardened by simple heating and quenching can be treated by the flame-hardening process. Carbon steels should contain at least 0.35 per cent carbon when any appreciable degree of hardness is desired, the best carbon range being 0.35 to 0.60 per cent. Steels with higher carbon content may be successfully flame-hardened, but greater care has to be exercised to prevent surface checking or cracking. The table lists a number of types of steel which have been successfully flame-hardened. The surface hardness that can be expected from flame-hardening any of these steels at least equals that which would result if furnace-hardened.

Pearlitic cast irons and malleable irons offer a broad field for the flame-hardening process since the wearing properties of cast iron surfaces are greatly improved by this process.

Applications and Methods.—Flame-hardening may be adapted to castings, forgings or rolled sections. Size is not a limiting factor and if the part is fabricated from material having the proper analysis and the sections requiring hardening are readily accessible, it can be flame-hardened.

TYPES OF STEELS SUITABLE FOR FLAME-HARDENING*

S.A.E. Carbon Steels	S.A.E. Manganese Steels	S.A.E. Nickel Steels	S.A.E. Nickel-Chromium Steels	S.A.E. Chromium Steels	S.A.E. Chromium-Vanadium Steels	S.A.E. Molybdenum Steels
1035	T1330	2330	3140	5140	6135	4130
1040	T1335	2335	X3140	52100	6140	X4130
X1040	T1340	2340	3145			4135
1045	T1345	2345	3230			4140
X1045		2350	3240			4340
1050			3335			4640
X1050			3340			
1055			3435			
X1055						
1060						
1095						

Miscellaneous — Carbon Vanadium and Carbon Molybdenum Steels, Malleable Iron, Cast Iron, and Graphitic Steel.

*As a guide to the type of steels, the S.A.E. steels are listed, but many other steels similar to these grades can also be flame-hardened.

From a mechanical standpoint, there are four methods of flame-hardening.

Stationary or Spot Hardening — This term is applied to operations in which the blowpipe and the work are stationary.

Progressive Method — In this method the flame traverses the work at a uniform rate. It finds applications to parts such as gear teeth, (see Fig. 461) track rails or lathe bed ways. In some instances a number of small parts are lined up and the entire group treated by the progressive method. A variation of this method might have the part moving while the flame remained stationary.

Spinning Method — To produce hardened bands on cylindrical surfaces, the part may be turned rapidly in front of multiflame heads or tips. When the part has reached the proper temperature, the flames are extinguished and the part is dropped into a water bath or a spray quench is turned upon it.

Progressive Spinning Method — In this case the flames traverse the work, followed by a spray quench, while the part is spinning. Usually more than one blowpipe or torch, depending upon the diameter of the object, is used.

To harden irregular contours it is sometimes necessary to employ specially designed heating heads or tips, or to do the hardening in sections. In the latter case, as in any other, care must be taken to avoid drawing a previously hardened area, or to keep such effects to a minimum.

Stress Relieving. — A low temperature heat treatment to relieve quenching stresses without materially reducing hardness should immediately follow flame-hardening. This may be accomplished in a heat-treating furnace or by means of an air or oil bath at temperatures from 350 to 400 deg. F.

Costs.—Computation of cost and gas consumption depends upon setup time, case depth, method, rate of flame travel, size and number of flames and relation of the surface to mass of the object treated. Owing to these variables only an approximation of cost can be made. A fair estimating figure for gas consumption is that 1/4 cu. ft. of each gas will harden one sq. in. of surface to a depth of about 1/8 in. Speed range is 3 to 10 in. per min.

TENTATIVE SPECIFICATIONS FOR IRON AND STEEL ARC WELDING ELECTRODES

This is a Tentative Standard and under the Regulations of the Cooperating Societies is subject to annual revision. Suggestions for revision should be addressed to the Headquarters of the A.S.T.M., 260 Broad Street, Philadelphia, Pa., or of the A.W.S., 33 W. 39th Street, New York, N. Y.

These specifications were prepared jointly by the American Welding Society and the American Society for Testing Materials,[1] and adopted by the A.W.S. Feb. 29, 1940.

Scope

1. (a) These specifications cover metal arc welding electrodes for the welding of carbon and low alloy steels, of welding quality.

(b) The electrodes are classified on the basis of usability and the ultimate tensile strength of all-weld-metal specimens in the stress relieved condition, as shown in Table 1.

Process

2. The electrodes may be made by any process that will fulfill the requirements of these specifications.

Standard Sizes

3. Standard sizes of electrodes are as shown in the table below. In all cases, standard size refers to the diameter of the core wire, which shall not vary more than ± .002″ from standard.

Diameter in Inches	Standard Lengths in Inches
1/16, .075 and 3/32	9 or 12 and 18*
7/64	12
1/8	14
5/32, 3/16, 7/32, 1/4	14 and 18
5/16 and 3/8	18

Chemical Composition

4. The electrodes shall be capable of depositing metal conforming to the following requirement as to chemical composition:

Sulphur, Max., per cent.. 0.04

Chemical Analysis

5. The sample for analysis shall be prepared as follows: A specimen of standard base metal (see Paragraph 13a) of sufficient size, shall be prepared, and a pad of five superimposed layers of weld metal deposited thereon. The fifth or top layer shall be ground or machined away and discarded. The sample for chemical analysis shall be obtained from the third and fourth layers.

Permissible Variations in Dimensions

6. (a) Covered electrodes for manual welding shall be bare or free from covering for a distance of about 1 inch, but not more than 1¼ inch, for making contact with the holder.

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[1] Under the standardization procedure of the two Societies, these specifications are under the jurisdiction of the A.S.T.M. Committee A-1 on Steel, and of the A.W.S. Filler Metal Specifications Committee.

*In this case, center gripping is standard. In all other cases, end gripping is standard.

(b) The arc end shall be sufficiently bare to permit easy striking of the arc, but the length of the bare portion of the arc end, measured from the end to the point where the full cross-section of the coating obtains, shall not exceed one core-wire diameter.

(c) Cut lengths shall not vary from that specified by more than 1/8 inch.

(d) The covering (coating) on covered electrodes shall be concentric to the extent that for all sizes of electrodes the maximum core-plus-one-coating dimension shall not exceed the minimum core-plus-one-coating dimension by more than 3 per cent. The concentricity shall be measured as follows:

The coating or covering shall be removed from one side of the electrode (care being taken to insure that no metal is removed from the core) at about the center of its length. The core-plus-one-coating dimension (which is the diameter of the core plus the thickness of the coating on one side) shall be measured with a micrometer. The coating shall be removed from the opposite side of the electrode at a point distant from the place where the coating was previously removed, and a similar measurement made. Two more pairs of measurements of the core-plus-one-coating dimension shall be made on planes at angles of 60° and 120° from the plane of the former measurements. The pair of measurements which shows the greatest percentage of variation shall determine the acceptability of the electrode.

Covered Electrode Requirements

7. (a) The coverings shall, when cool, have sufficient electrical resistance to effectively insulate against a potential difference of 100 volts.

(b) The slag produced shall be readily removable.

Workmanship

8. (a) Lightly coated electrodes and the core of covered electrodes shall be of uniform quality and free from injurious segregation, oxides, pipe, seams, or other irregularities.

(b) On covered electrodes, the coverings shall be such that they are not readily damaged by ordinary handling and shall be of commercially uniform thickness and shall present a workmanlike appearance. Coverings shall be free from injurious scabs, blisters, abnormal pockmarks, bruises or other surface defects.

Finish

9. The surface of bare electrodes and the core of covered electrodes shall be smooth and free from harmful scale, oil or grease.

Packing

10. Electrodes shall be suitably packed, wrapped, boxed or crated to insure against injury during shipment or storage, as follows:

(a) Bundles of 50 lbs. net weight.
(b) Boxes of 25 or 50 lbs. net weight, and
(c) Coils or reels of approximately 150 or 200 lbs. net weight.

Marking

11. All bundles, boxes, coils or reels shall be legibly marked and bear the following information:

(a) Classification.
(b) Manufacturer's name and trade designation.
(c) Guarantee.

Guarantee

12. The manufacturer shall make tests at frequent intervals in accordance with the method prescribed in these specifications, and shall guarantee that the electrodes in all sizes and classes meet the requirements of these specifications and each container shall be so marked.

Guarantee Tests

13. For guarantee purposes, tests shall be made as prescribed below:—

(a) The steels to be used for test plates shall be either of the following grades:

(1) Standard Specifications for Carbon-Steel Plates for Stationary Boilers

TABLE I

Tensile Requirements for 5/32, 3/16, and 7/32 In. Deposited Metal (b)

Electrode Classification No.	Capable of producing satisfactory welds in position shown (c)	General Description	Treatment of welded specimen (a)	All Weld Tension (b)	
				Lbs. p.s.i.	% El. in 2"
E7010	V, F, OH, H	Heavy covering, useful with D.C. electrode positive only.	SR NSR	70,000 75,000	22 17
E7011	F, V, OH, H	Heavy covering, useful with D.C. either polarity, or with A.C.	SR NSR	70,000 75,000	22 17
E7020	H-Fillets, F	Heavy covering usually used with electrode negative, or A.C. for fillets, or electrode positive or A.C. for flat welding.	SR NSR	70,000 75,000	25 20
E7030	F	Heavy covering usually used with electrode positive D.C., or with A.C.	SR NSR	70,000 75,000	25 20
E6010	F, V, OH, H	Heavy covering useful with D.C. electrode positive only.	SR NSR	60,000 65,000	27 22
E6011	F, V, OH, H	Heavy covering, useful D.C. either polarity, or with A.C.	SR NSR	60,000 65,000	27 22
E6012	F, V, OH, H	Heavy covering usually used with electrode negative D.C., or on A.C.	SR NSR	60,000 65,000	22 17
E6013	F, V, OH, H	Heavy covering usually used on A.C.	SR NSR	60,000 65,000	22 17
E6020	H-Fillets, F	Heavy covering usually used with electrode negative or A.C. for fillets and electrode positive or A.C. for flat welding.	SR NSR	60,000 65,000	30 25
E6030	F	Heavy covering usually used with electrode positive on D.C., or with A.C.	SR NSR	60,000 65,000	30 25
E4510	F, V, OH, H	Wire with coating applied before drawing.	NSR	45,000	5
E4511	F, V, OH, H	Wire with light coating applied after drawing.	NSR	45,000	5
E4520	H-Fillets, F	Wire with coating applied before drawing.	NSR	45,000	5
E4521	H-Fillets, F	Wire with light coating applied after drawing.	NSR	45,000	5

NOTES FOR TABLE I

The notations SR and NSR mean stress-relieved and non stress-relieved.

(a) Stress-relieving where called for in these specifications is for the purpose of developing the fundamental properties of the weld metal unaltered by locked-up stress. Values obtained from stress-relieved welded specimens are about 5 per cent lower in tensile strength and 10 to 20 per cent higher in ductility than those of non-stress-relieved specimens. The fact that an electrode test requires stress-relief signifies only that it must develop the strength required regardless of stress-relief, and not that stress-relief must always be used in actual work. Stress-relieving shall be within the range of 1150°F. ± 25° for at least one hour per 1 in. of thickness. Specimen shall be heated at the rate of 300° — 350°F. per hour; shall be cooled at the same rate to 300°F. No specimen shall be heated for less than 1 hour.

(b) The tensile strength of the deposited metal from 1/8 in. electrodes shall be that prescribed in Table I increased by 5% and that from 1/4 in. and larger electrodes shall be the tensile strength prescribed in Table I decreased by 5%

The ductility of the deposited metal from 1/8 in. electrodes shall be that prescribed in Table I decreased by 10%, and that from 1/4 in. and larger electrodes shall be the ductility prescribed in Table I increased by 10%.

(c) The symbols F, V, OH, H and H-fillets indicate welding positions and shall mean as follows:

F — Flat
V — Vertical
H — Horizontal
OH — Overhead
H-Fillets — Horizontal Fillets

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and Other Pressure Vessels, of the American Society for Testing Materials (A.S.T.M. Designation A70-36, or current revision thereof).

(2) Standard Specifications for Steel for Bridges, of the American Society for Testing Materials (A.S.T.M. Designation A7-36, or current revision thereof).

(b) For electrodes smaller than 1/8-in., the all-weld-metal tensile test is not practical and the strength of these sizes shall be judged by the strength of 1/8-in. or larger electrodes.

(c) For 1/8-in. and larger electrodes, a test plate shall be prepared as shown in Fig. 462. The plate shall be insulated by 1/2-in. of asbestos during welding. After joint has been tacked, assembly shall be heated in boiling water for five minutes prior to welding. After depositing each pass, the plate shall be left on asbestos to cool in still air for the length of time prescribed in Fig. 462. Then, immediately, the plate shall be immersed in boiling water for five minutes and the work proceeded with. After the last pass, the plate shall be left on asbestos until cold. The work shall be done at room temperature of 65°F. minimum and in the flat position. Weaving shall be width of groove up to four times diameter of the core-wire, when the layer shall be divided into two passes overlapping.

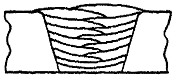
Test plates shall be so supported that warping due to welding shall not throw the finished test plate out of line by an angle of over 5 deg. If plates are warped, they shall be straightened cold before being stress-relieved where required.

(d) Two all-weld-metal tensile specimens shall be machined from the finished test plate as shown in Fig. 462, and shall, when tested, meet the requirements for tensile strength and percentage elongation as stated in Table I.

(e) If one of the specimens fractures outside the middle third or if either specimen fails to pass, another plate shall be welded and both specimens shall pass.

(f) Electrodes in each classification shall be capable of producing satisfactory welds which will meet the all-weld-metal tensile test requirements as stated in Table I, for the type or types of current and the welding position or positions listed in the same table. Welding positions shall be determined from Fig. 25.

(g) For each classification and size of electrode, specimens of welding shall be prepared with the type of current and the welding positions listed in Table I, and the height of the reinforcement on butt welds, and the size and concavity or convexity of fillet welds shall be measured with a gauge similar to that shown in Fig. 463, in the manner described in Figs. 464-467, and the results recorded. The result shall be furnished by the manufacturer or vendor to the purchaser upon request.

ELECTRODE SIZE/ INCHES	"I" TEST PLATE THICKNESS INCHES	NO. OF LAYERS	DIA "A" OF TENSILE TEST SPECIMEN	DIMENSIONS OF TEST PLATE AND TENSILE TEST SPECIMEN B	C	D	E	F	G	H	J	K	TIME TO WAIT AFTER DEPOSITING LAYER AND BEFORE PREHEATING FOR NEXT LAYER
1/8	1/2		.252	1	3/8	2 1/2	1/2	3/16	1 1/4	9 1/2	1/4	1/4	10 MIN.
5/32	3/4		.505									3/8	15 "
3/16	3/4		.505									3/8	15 "
7/32	3/4		.505	2	3/4	4 1/4	3/4	3/8	2 1/4	12 1/2	5/8	3/8	15 "
1/4	1	LAYERS NOT TO EXCEED 1/8 INCH IN THICKNESS	.505									1/2	20 "
5/16	1 1/4		.505									1/2	25 "
3/8	1 1/2		.505									1/2	30 "

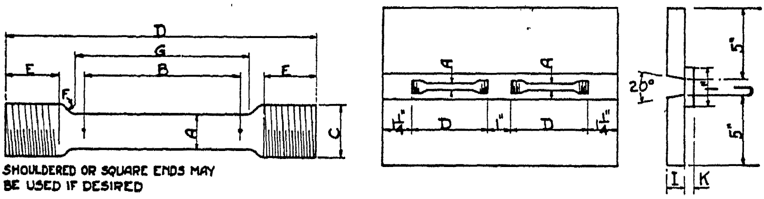


Fig. 462.

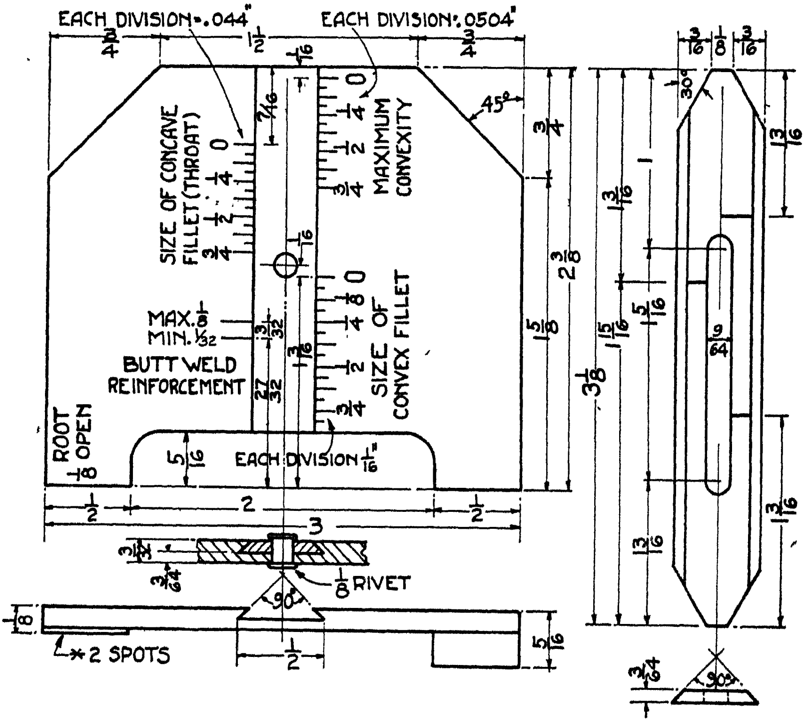


Fig. 463. Butt and fillet weld gauge.

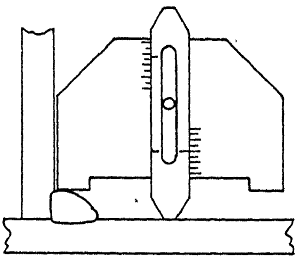
NOTES
1. All parts of this gauge shall be made of corrosion-resistant steel.
2. Pointer shall be a "push fit" in gauge plate and shall operate smoothly.
3. All lettering and graduations on gauge shall be made by engraving.

Publisher's Note: At time of going to press, this gauge has not been formally approved. Changes or improvements may be made in its design.

BUTT AND FILLET WELD GAUGE

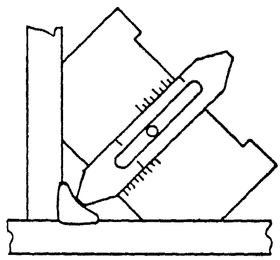
INSTRUCTIONS FOR USE

To determine the size of a convex fillet weld, place gauge against the toe of shortest leg of the fillet and slide pointer out until it touches structure. Read leg length or "size of convex fillet" on face of gauge. See Fig. 464.



SIZE OF CONVEX FILLET

Fig. 464.

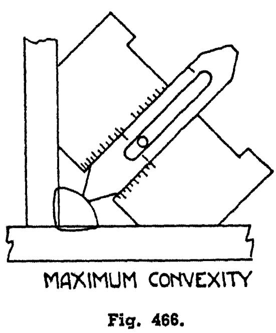


SIZE OF CONCAVE FILLET

Fig. 465.

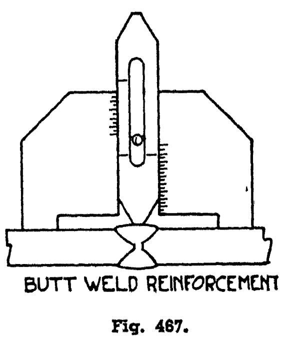
To determine the size of a concave fillet weld, place gauge against structure and slide pointer out until it touches the face of fillet weld. Read throat dimension, or "size of concave fillet," on face of gauge. See Fig. 465.

After the size of a convex fillet weld has been determined place gauge against structure and slide pointer out until it touches face of fillet weld. The maximum convexity should not be greater than indicated by "maximum convexity" for the size of fillet being checked. See Fig. 466.



MAXIMUM CONVEXITY

Fig. 466.



BUTT WELD REINFORCEMENT

Fig. 467.

To determine reinforcement of groove welds, place gauge so that reinforcement will come between legs of gauge and slide pointer out until it touches the face of the weld. The amount of reinforcement shall be that permitted on the face of the gauge. See Fig. 467.

S. A. E. STEEL NUMBERING SYSTEM

A numeral index system is used to identify the compositions of the S. A. E. steels, which makes it possible to use numerals on shop drawings and blueprints that are partially descriptive of the composition of material covered by such numbers. The first digit indicates the type to which the steel belongs; thus '1–' indicates a carbon steel; '2–' a nickel steel and '3–' a nickel chromium steel. In the case of the simple alloy steels the second digit generally indicates the approximate percentage of the predominant alloying element. Usually the last two or three digits indicate the average carbon content in 'points', or hundredths of 1 per cent. Thus '2340' indicates a nickel steel of approximately 3 per cent nickel (3.25 to 3.75) and 0.40 per cent carbon (0.35 to 0.45); and '71360' indicates a tungsten steel of about 13 per cent tungsten (12 to 15) and 0.60 per cent carbon (0.50 to 0.70).

In some instances, in order to avoid confusion it has been found necessary to depart from this system of identifying the approximate alloy composition of a steel by varying the second and third digits of the number. An instance of such departure is the steel numbers selected for several of the corrosion and heat resisting alloys.

The basic numerals for the various types of S. A. E. steel are

Type of Steel	*Numerals (and Digits)*
Carbon Steels	1xxx
Plain Carbon	10xx
Free Cutting, (Screw Stock)	11xx
Free Cutting, Manganese	X13xx
High Manganese	T13xx
Nickel Steels	2xxx
0.50 Per Cent Nickel	20xx
1.50 Per Cent Nickel	21xx
3.50 Per Cent Nickel	23xx
5.00 Per Cent Nickel	25xx
Nickel Chromium Steels	3xxx
1.25 Per Cent Nickel, 0.60 Per Cent Chromium	31xx
1.75 Per Cent Nickel, 1.00 Per Cent Chromium	32xx
3.50 Per Cent Nickel, 1.50 Per Cent Chromium	33xx
3.00 Per Cent Nickel, 0.80 Per Cent Chromium	34xx
Corrosion and Heat Resisting Steels	30xxx
Molybdenum Steels	4xxx
Chromium	41xx
Chromium Nickel	43xx
Nickel	46xx and 48xx
Chromium Steels	5xxx
Low Chromium	51xx
Medium Chromium	52xxx
Corrosion and Heat Resisting	51xxx
Chromium Vanadium Steels	6xxx
Tungsten Steels	7xxx and 7xxxx
Silicon Manganese Steels	9xxx

Prefixes

The prefix 'X' is used in several instances to denote variations in the range of manganese, sulphur or chromium.

The prefix 'T' is used with the Manganese Steels (1300 Series) to avoid confusion with steels of somewhat different manganese range that have been identified by the same numerals but without the prefix.

CHEMICAL COMPOSITIONS

Carbon Steels

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulfur Max.
1010	0.05–0.15	0.30–0.60	0.045	0.055
1015	0.10–0.20	0.30–0.60	0.045	0.055
X1015	0.10–0.20	0.70–1.00	0.045	0.055
1020	0.15–0.25	0.30–0.60	0.045	0.055
X1020	0.15–0.25	0.70–1.00	0.045	0.055
1025	0.20–0.30	0.30–0.60	0.045	0.055
X1025	0.20–0.30	0.70–1.00	0.045	0.055
1030	0.25–0.35	0.60–0.90	0.045	0.055
1035	0.30–0.40	0.60–0.90	0 045	0.055
1040	0.35–0.45	0.60–0.90	0.045	0.055
X1040	0.35–0.45	0.40–0.70	0.045	0.055
1045	0.40–0.50	0.60–0.90	0.045	0.055
X1045	0.40–0 50	0.40–0.70	0.045	0.055
1050	0.45–0.55	0.60–0.90	0.045	0.055
X1050	0.45–0.55	0.40–0.70	0.045	0.055
1055	0.50–0.60	0.60–0.90	0.040	0.055
X1055	0.50–0.60	0.90–1.20	0.040	0.055
1060	0.55–0.70	0.60–0.90	0.040	0.055
1065	0.60–0.75	0.60–0.90	0.040	0.055
X1065	0.60–0.75	0.90–1.20	0.040	0.055
1070	0.65–0.80	0.60–0.90	0.040	0.055
1075	0.70–0.85	0.60–0.90	0.040	0.055
1080	0.75–0.90	0.60–0.90	0.040	0.055
1085	0.80–0.95	0.60–0.90	0.040	0.055
1090	0.85–1.00	0.60–0.90	0.040	0.055
1095	0.90–1.05	0.25–0.50	0.040	0.055

Free Cutting Steels

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus Range	Sulfur Range
1112	0.08–0.16	0.60–0.90	0.09–0.13	0.10– 0.20
X1112	0.08–0.16	0.60–0.90	0.09–0.13	0.20– 0.30
1115	0.10–0.20	0.70–1.00	0.045 max.	0.075–0.15
1120	0.15–0.25	0.60–0.90	0.045 max.	0.075–0.15
X1314	0.10–0.20	1.00–1.30	0.045 max.	0.075–0.15
X1315	0.10–0.20	1.30–1.60	0.045 max.	0.075–0.15
X1330	0.25–0.35	1.35–1.65	0.045 max.	0.075–0.15
X1335	0.30–0.40	1.35–1.65	0.045 max.	0.075–0.15
X1340	0.35–0.45	1.35–1.65	0.045 max.	0.075–0.15

Nickel Steels[1]

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Nickel Range
2015	0.10–0.20	0.30–0.60	0.040	0.050	0.40–0.60
2115	0.10–0.20	0.30–0.60	0.040	0.050	1.25–1.75
2315	0.10–0.20	0.30–0.60	0.040	0.050	3.25–3.75
2320	0.15–0.25	0.30–0.60	0.040	0.050	3.25–3.75
2330	0.25–0.35	0.50–0.80	0.040	0.050	3.25–3.75
2335	0.30–0.40	0.50–0.80	0.040	0.050	3.25–3.75
2340	0.35–0.45	0.60–0.90	0.040	0.050	3.25–3.75
2345	0.40–0.50	0.60–0.90	0.040	0.050	3.25–3.75
2350	0.45–0.55	0.60–0.90	0.040	0.050	3.25–3.75
2515	0.10–0.20	0.30–0.60	0.040	0.050	4.75–5.25

Nickel Chromium Steels[1]

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Nickel Range	Chromium Range
3115	0.10–0.20	0.30–0.60	0.040	0.050	1.00–1.50	0 45–0.75
3120	0.15–0.25	0.30–0.60	0.040	0.050	1.00–1.50	0.45–0.75
3125	0.20–0.30	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3130	0.25–0.35	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3135	0.30–0.40	0.50–0.80	0.040	0.050	1.00–1.50	0.45–0.75
3140	0.35–0.45	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0 75
X3140	0.35–0.45	0.60–0.90	0.040	0.050	1.00-1.50	0.60–0.90
3145	0.40–0.50	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
3150	0.45–0.55	0.60–0.90	0.040	0.050	1.00–1.50	0.45–0.75
3215	0.10–0.20	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3220	0.15–0.25	0.30–0.60	0.040	0.050	1.50–2 00	0.90–1.25
3230	0.25–0.35	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3240	0.35–0.45	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3245	0.40–0.50	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3250	0.45–0.55	0.30–0.60	0.040	0.050	1.50–2.00	0.90–1.25
3312	max. 0.17	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3325	0.20–0.30	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3335	0.30–0.40	0.30–0.60	0.040	0.050	3.25–3.75	1.25–1.75
3340	0.35–0.45	0.30–0.60	0.040	0 050	3.25–3.75	1.25–1.75
3415	0.10–0.20	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95
3435	0.30–0.40	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95
3450	0.45–0.55	0.30–0.60	0.040	0.050	2.75–3.25	0.60–0.95

[1] Silicon range of all S.A.E. basic open hearth alloy steels shall be 0.15—0.30. For electric and acid open hearth alloy steels, the silicon content shall be 0.15 minimum.

Manganese Steels[2]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.
T1330	0.25–0.35	1.60–1.90	0.040	0.050
T1335	0.30–0.40	1.60–1.90	0.040	0.050
T1340	0.35–0.45	1.60–1.90	0.040	0.050
T1345	0.40–0.50	1.60–1.90	0.040	0.050
T1350	0.45–0.55	1.60–1.90	0.040	0.050

Molybdenum Steels[2]

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Nickel Range	Molybdenum Range
4130	0.25–0.35	0.50–0.80	0.040	0.050	0.50–0.80	—.—	0.15–0.25
X4130	0.25–0.35	0.40–0.60	0.040	0.050	0.80–1.10	—.—	0.15–0.25
4135	0.30–0.40	0.60–0.90	0.040	0.050	0.80–1.10	—.—	0.15–0.25
4140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10	—.—	0.15–0.25
4150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10	—.—	0.15–0.25
4340	0.35–0.45	0.50–0.80	0.040	0.050	0.50–0.80	1 50–2.00	0.30–0.40
4345	0.40–0.50	0.50–0.80	0.040	0.050	0.60–0.90	1.50–2.00	0.15–0.25
4615	0.10–0.20	0.40–0.70	0.040	0.050	—.—	1.65–2.00	0.20–0.30
4620	0.15–0.25	0.40–0.70	0.040	0.050	—.—	1.65–2.00	0.20–0.30
4640	0.35–0.45	0.50–0.80	0.040	0.050	—.—	1.65–2.00	0.20–0.30
4815	0.10–0.20	0.40–0.60	0.040	0.050	—.—	3.25–3.75	0.20–0.30
4820	0.15–0 25	0.40–0.60	0.040	0.050	—.—	3.25–3.75	0.20–0.30

Chromium Vanaduim Steels[2]

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Vanadium	
						Min.	Desired
6115	0.10–0.20	0.30–0.60	0.040	0.050	0.80–1.10	0.15	0.18
6120	0.15–0.25	0.30–0.60	0.040	0.050	0.80–1.10	0.15	0.18
6125	0.20–0.30	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6130	0.25–0.35	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6135	0.30–0.40	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6145	0.40–0.50	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10	0.15	0.18
6195	0.90–1.05	0.20–0.45	0.030	0.035	0.80–1.10	0.15	0.18

[2] Silicon range of all S. A. E. basic open hearth alloy steels shall be 0.15–0.30. For electric and acid open hearth alloy steels, the silicon content shall be 0.15 minimum.

Chromium Steels[3]

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Chromium Range
5120	0.15–0.25	0.30–0.60	0.040	0.050	0.60–0.90
5140	0.35–0.45	0.60–0.90	0.040	0.050	0.80–1.10
5150	0.45–0.55	0.60–0.90	0.040	0.050	0.80–1.10
52100	0.95–1.10	0.20–0.50	0.030	0.035	1.20–1.50

Tungsten Steels[3]

S.A.E. No.	Carbon Range	Manganese, Max.	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Tungsten Range
71360	0.50–0.70	0.30	0.035	0.040	3.00–4.00	12.00–15.00
71660	0.50–0.70	0.30	0.035	0.040	3.00–4.00	15.00–18.00
7260	0.50–0.70	0.30	0.035	0.040	0.50–1.00	1.50– 2.00

Silicon Manganese Steels

S. A. E. No.	Carbon Range	Manganese Range	Phosphorus, Max.	Sulfur, Max.	Silicon Range
9255	0.50–0.60	0.60–0.90	0.040	0.050	1.80–2.20
9260	0.55–0.65	0.60–0.90	0.040	0.050	1.80–2.20

Corrosion and Heat Resisting Alloys

S. A. E. No.	Carbon, Max.	Manganese, Max.	Silicon, Max.	Phosphorus, Max.	Sulfur, Max.	Chromium Range	Nickel Range
30905	0.08	0.20–0.70	0.75	0.030	0.030	17.00–20.00	8.00–10.00
30915	0.09–0.20	0.20–0.70	0.75	0.030	0.030	17.00–20.00	8.00–10.00
51210	0.12	0.60	0.50	0.030	0.030	11.50–13.00	——
X51410	0.12	0.60	0.50	0.030	0.15–0.50	13.00–15.00	——
51335	0.25–0.40	0.60	0.50	0.030	0.030	12.00–14.00	——
51510	0.12	0.60	0.50	0.030	0.030	14.00–16.00	——
51710	0.12	0.60	0.50	0.030	0.030	16.00–18.00	——

[3] Silicon range of all S. A. E. basic open hearth alloy steels shall be 0.15–0.30. For electric and acid open hearth alloy steels, the silicon content shall be 0.15 minimum.

PART VI

WELDED STEEL CONSTRUCTION — MACHINE DESIGN

AN OFFER
BY THE LINCOLN ELECTRIC COMPANY—PUBLISHERS OF THIS BOOK—THAT GUARANTEES SAVINGS TO ANY FABRICATOR OR MANUFACTURER OF MACHINERY

If, by the use of arc welding, a properly designated man in your business cannot make savings greater than his salary, The Lincoln Electric Company, publishers of this book, will make up to you in cash the difference between such savings as are actually effected and the salary of the man designated to do the development work. The following terms and conditions to govern this offer:

1. You to advise The Lincoln Electric Company of your desire to accept this offer.

2. You to employ or designate in your own organization a man whom both you and The Lincoln Electric Company agree upon as qualified to carry on development work by arc welding.

3. This man so designated to devote his entire time to this development work.

4. You to give authority to the man so designated to proceed with the design, development and manufacture or fabrication by means of arc welding, of products or parts of products manufactured by you.

5. The man so designated, and his work, to be accessible at all times to Lincoln development engineers for consultation and suggestions.

6. Your regular cost accounting system, or variation thereof as agreed upon between us, to be applied to his work over a period of two years. If at the end of such period your records do not show savings over former methods greater than the salary of the man so designated above, The Lincoln Electric Company will pay to you in cash the difference between such savings as are actually effected and the salary of the man, this amount under any conditions not to exceed the salary of the man.

PART VI

WELDED STEEL CONSTRUCTION—MACHINE DESIGN

INTRODUCTION

Executive Policy

The success of a manufacturer with welded design is influenced to a large extent by executive policy.

The president of one company, a large manufacturer of welded machinery, makes this statement: "To those organizations which have made a half-hearted attempt at welded construction, or to those considering its use, we suggest that welding development and fabrication be put under the supervision of an executive with authority to act on his own responsibility."

Appoint a Welding Supervisor

If the executive cannot devote time to this sort of thing, it is desirable that he appoint some man to push welded design and to report to the executive on all matters relating to the changeover program.

This plan calls for a man with these qualifications: (1) He has a deep-seated faith in the ability of arc welding to cut costs and improve product quality. (2) He has the zeal and initiative necessary for leadership against the forces of Tradition. (3) He has practical knowledge and experience in welded design and production.

Based on the experiences of scores of manufacturers, this plan has proved highly successful.

The Designing Approach

Change One Part at a Time

Experience has shown that the most effective and economical approach to redesign for arc welding is to change over *one part at a time.* This gradual transition is simple and inexpensive. Then, after one part has been designed, think about another—say the part to which the first one is attached. Here, the designer may also be able to take advantage of the simplicity of welding as a means of attachment. Then proceed in like manner, one part at a time until the entire product is as fully welded as possible.

Meet the Functional Requirements

In designing for welded steel construction, do not try to duplicate the former design of conventional construction. This procedure would be wasteful and the result generally would be far from attractive.

Approach the problem naively, open-mindedly; forget about the former construction and simply design to meet the functional requirements of the part. Use steel plate, bars, angles, channels and other standard shapes, pressed steel parts or steel castings as required to

meet the actual stress and service requirements. And in doing so, take advantage of the fact that steel is three to six times as strong and two and one-half times as rigid as the same section of ordinary cast iron.

Proper Design Assures Proper Appearance

The sloping sides and rounded corners of the cast machine parts, to which we have been accustomed, are not the result of designing for beauty's sake. These slopes and curves are the result of a casting necessity—to permit withdrawal of the pattern from the sand.

Obviously, since these rounded effects are not required for a welded design, and since its material can be placed accurately where required to resist stresses, the proportions and appearance of the welded design are going to be quite different than for the castings they replace. In many cases the difference will be as apparent as the contrast between 1920 model and 1940 model automobiles.

There is a strong and growing preference for industrial designs of the type made possible by welding. This public opinion is probably the result of the fact that streamlined trains, steel household equipment, all steel auto bodies and many other modern products and structures are recognized for qualities such as *speed, safety, utility* and *economy,* far surpassing the traditional designs they replace. The average buyer of machinery and equipment has the same viewpoint. Give him a sensible looking design that will outperform the former design and he will consider it beautiful.

Consider appearance at the start from a general standpoint—only as it affects the selection of the type of steel members to be employed—such as formed plate or structural shapes. Analyze the functions and service problems and lay stress on making an accurate design. As a final step, minor refinements can be made if necessary, to provide a most pleasing appearance.

Design for Production Economy

Another suggestion is to take full advantage of the engineering freedom made possible by welding. The designer should remember that various combinations of metals and alloys can be used in a design to gain utmost economy and serviceability. Moreover, many shapes and sizes of material can be used.

Minimize the amount of welding required by specifying bent plate and pressed steel parts where possible.

Design to facilitate welding by providing easy access to joints.

Bear in mind that deposited metal of the shielded arc process is actually superior to the parent metal and that for maximum economy, over-welding should be avoided.

Production Practices

Use Modern Equipment

Adequate production facilities are essential to a program of welded design. Do not skimp in this regard. Invest in modern dependable equipment. The resultant savings more than justify the investment

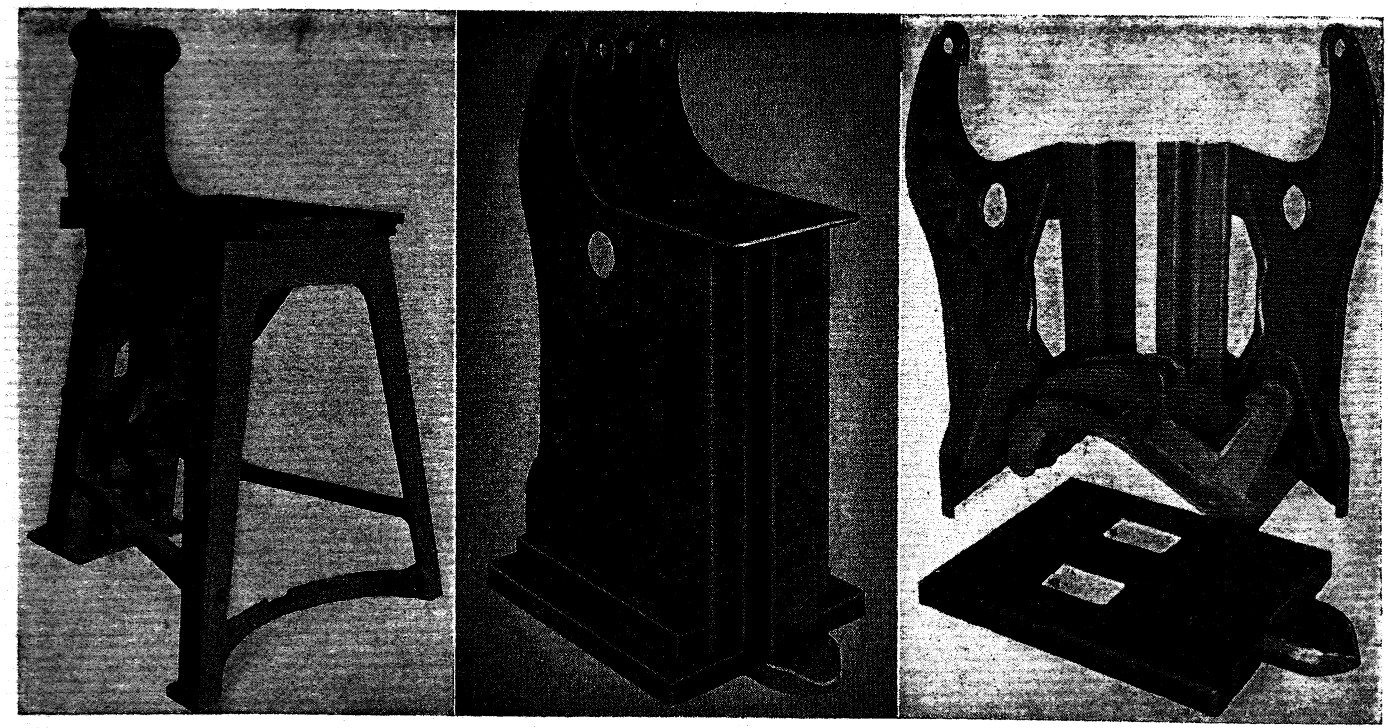


Fig. 468. Design for Functional Requirements. In the case of this garment pressing machine frame, design for functional requirements with welded steel produced the results shown. The former cast and bolted design is shown on the left. The welded one-piece frame (center), comprising the fabricated base, pressed steel sides and cast steel top, shown at the right, saves 16% in user's floor space, provides greater rigidity for 40% faster operation and saves production costs.

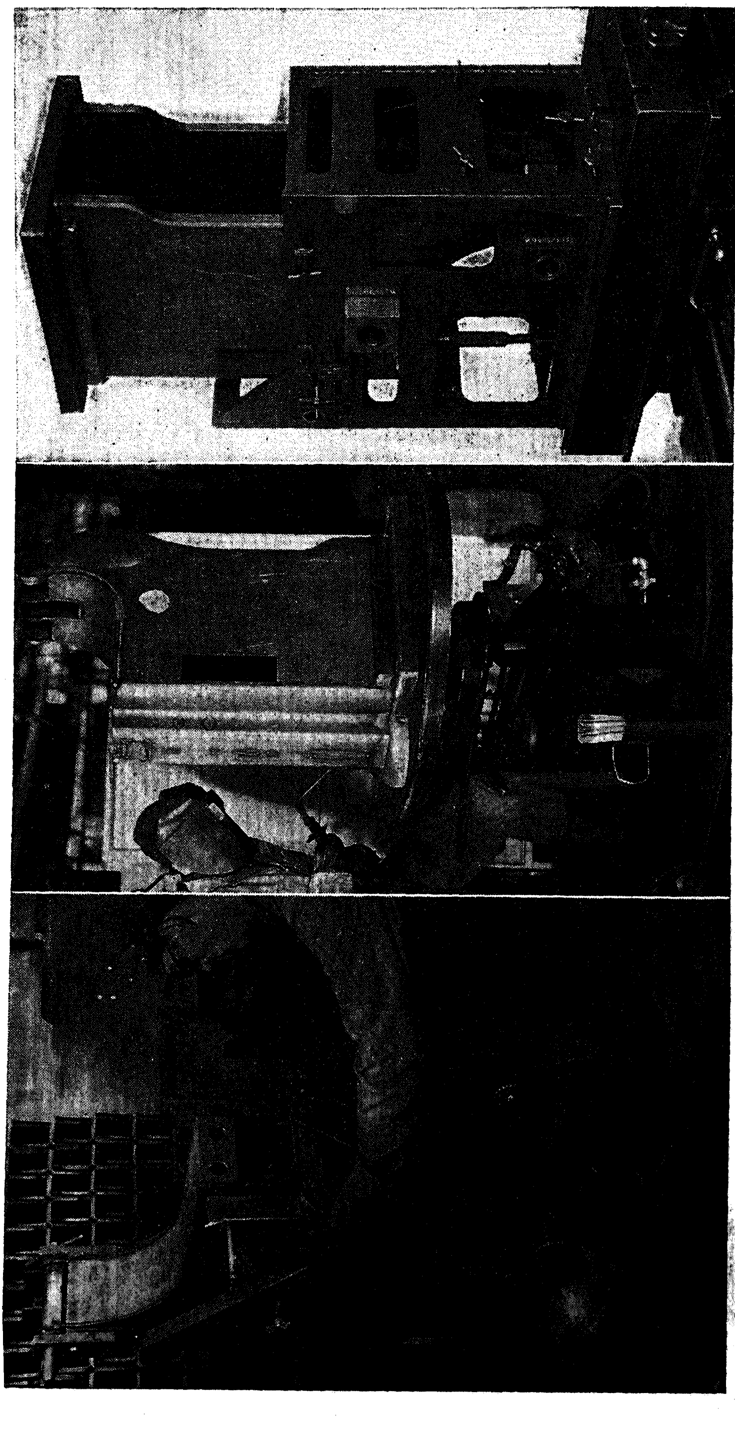


Fig. 469. Use Modern Production Methods. Some of the welded steel shop equipment used for economical manufacture of welded frames such as shown in Fig. 468. Left: Jig used for fitting-up and tack-welding parts. Center: Work turn-table used for assembly to assure speedy welding. Right: Welded fixture facilities machining of top casting on welded frame.

cost. This applies not only to welding equipment but to bending and forming equipment, work positioners, shears, cutting equipment and other related machinery of the modern weldery.

Use Efficient Methods

Bear in mind the basic principles of sound welding practice. Bend and form where feasible and more economical to eliminate the need for welded joints. Use set-up jigs to minimize welding interruptions and cut labor costs. Use work positioners and large size electrodes to get maximum deposit rates for lowest cost and quality results. These and other procedure pointers are discussed fully in this chapter and in Chapter III.

* * * * *

Design for welding approached along these proven lines assures ***better products at lower cost.***

For additional information on Machine Design.—29 Chapters . . . 382 pages . . . 190 illustrations of practical case studies in welded machine design are contained in the book, "Arc Welding in Design, Manufacture and Construction," published by The James F. Lincoln Arc Welding Foundation.

DESIGNING FOR WELDED STEEL CONSTRUCTION

The design of machinery involves two major considerations. First—load conditions or service life which must be met in an adequate manner. Second—the cost must be low. This cost usually is a reduced cost for the same service life or performance, or it may be a superior service life at the original cost. Cost enters into every item and will be discussed with each one, the various items being the constituent parts of the machine.

The designer must keep in mind at all times that the machine he is laying out is to be sold, and is to be used profitably by his customer. The ability to visualize the machine from the drafting board of the designer, through his shop and on to the purchaser and its final use, is of extreme value and importance in the working out of a design.

As every design may be considered as consisting of the functional specifications or service requirements and the limiting dimensions, or requirements (weight is considered a dimension), the major problem may be divided into separate problems for each unit of the machine—and each of these units may be further divided into elementary or component parts, each of which may be viewed as a separate problem. And since it is from the build-up or assembly of these elementary or basic parts that a machine is produced, these basic parts are of prime importance.

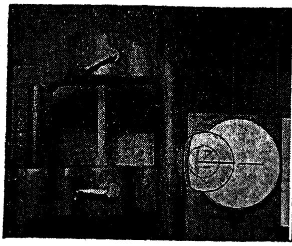
The first basic unit is the selection of the most suitable, practical and economical material because the entire design usually is governed by the material selected. Consideration, therefore, must be given to materials and the influence of each on performance, service life

and cost—the latter involving size, shape, weight, production methods and operating costs.

Two materials are considered in this section—cast iron and welded rolled steel. *This discussion refers to mild steel (not alloyed) and ordinary cast iron (not alloyed).* Formerly, cast iron was used generally for making parts. Some designers have become so accustomed to its limitations that they expect such limitations in other materials and design accordingly. It is therefore essential to discuss fully in comparative form the design limitations of cast iron and rolled structural steel shapes in order to present realistically the proper values of these materials as machinery design media. (See Page 400.)

In general, mild rolled steel as compared to ordinary cast iron is—

300% to 600% Stronger in Tensile Working Strength—The two equal-sized bars shown in the testing machine were pulled to failure. The cast iron bar in Fig. 470 broke at 16,420 lbs. per sq. in. The mild steel bar in Fig. 471 withstood a loading up to 61,800 lbs. per sq. in.



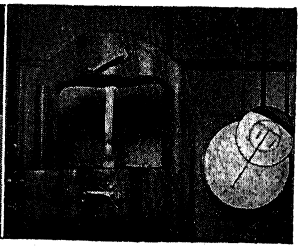


Fig. 470. Cast iron—16,420 lbs. per sq. in. Fig. 471. Steel—61,800 lbs. per sq. in.

Approximately 250% Stiffer.—Two bars of equal size, one steel and one cast iron, are fixed at one end. Equal weight is then placed on each bar at the unsupported ends. (See Fig. 472.) The cast iron bar is deflected 2½ times as much as the steel bar.

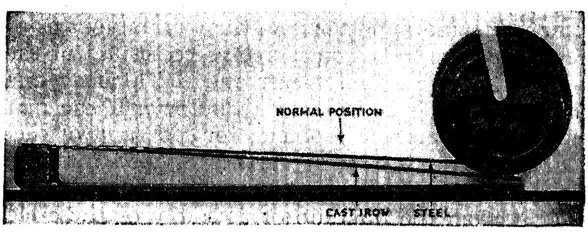


Fig. 472. Steel bar deflected 40% as much as cast iron bar.

Up to high unit stresses, steel returns to its original shape upon removal of the load. Cast iron takes a permanent set at very low unit stresses. Above a few thousand pounds per square inch the part is permanently deformed.

Approximately 300% More Resistant to Fatigue.—Steel has a fatigue resistance of 28,000 to 32,000 lbs. per sq. in. (Rotating beam test.) Cast iron subjected to the same unit stresses breaks in a very short time.

Fig. 473.

Fig. 474.

Much More Resistant to Shock and Impact.—One blow of the 9-pound sledge shattered the cast iron part. Twenty blows of the sledge merely bent the duplicate part which is built of steel. (See Fig. 474.)

Steel is Ductile.—A characteristic of great value. A brittle material is not desirable.

Steel is Uniform, Dependable.—Every ounce of rolled steel has definite physical qualities. Its homogeneous structure makes possible more economical and more dependable designs.

Steel is Approxiatemly 50% Lower in Cost than cast iron.

Steel Fulfills Practically All Design Requirements.

Advantages of Welded Fabrication

The mechanical or physical characteristics of these materials should be considered hand in hand with the methods of fabrication.

Welded fabrication has certain very definite advantages.

Design Costs are Lower.—The use of standard steel shapes and standard weld symbols makes designing for welded steel speedy and simple. Considerable detailing is required for cast construction.

No Patterns are Required.—Cost of pattern drawings, pattern making, pattern storage and pattern repairing are eliminated. Since there are no pattern charges, improvements can be applied to existing design immediately. Welded designs are fabricated directly from rolled shapes and formed plate.

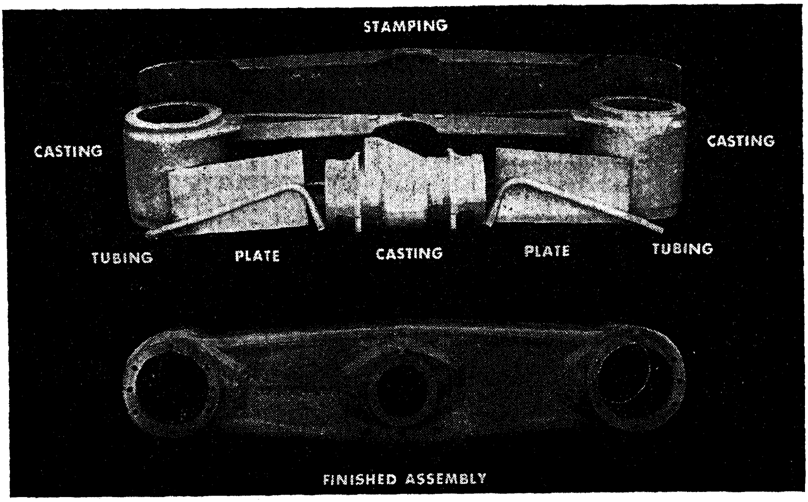


Fig. 475. Component parts and finished assembly for a rocker beam used on an earth-moving buggy. This illustrates the engineering freedom of welded design permitting the use of a wide variety of steel shapes for maximum manufacturing and service economy.

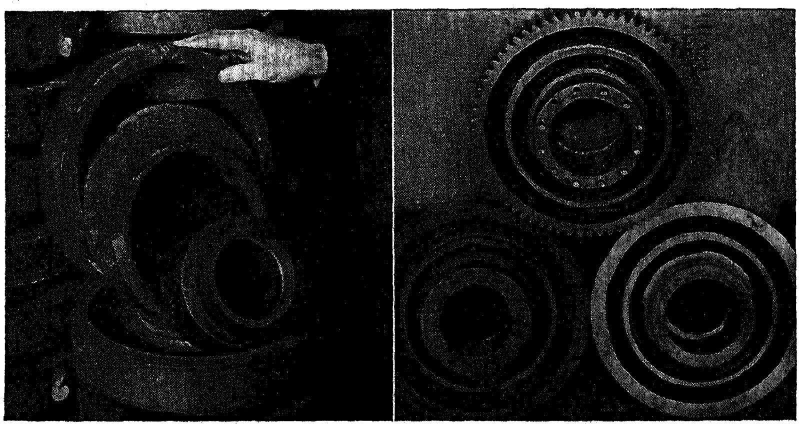


Fig. 476. This application illustrates how steel of various chemical and physical properties can be combined by welding for greatest manufacturing and service economy. Left: Component parts for a spur gear blank. Hub and oil ring in foreground, subjected to abrasion in service, are made from medium carbon steel. For maximum strength, the web is made from high tensile steel. To facilitate cutting of teeth the rim is made from mild steel and later case hardened. Right: Rough gear blank is shown at the lower left and next to it the machined blank. On top is the completed gear.

Material Costs are Lower.—Using a stronger, stiffer, more uniform material, fewer pounds are required. Since rolled steel costs $\frac{1}{4}$ to $\frac{1}{2}$ as much per pound as a casting, the cost of material is cut as much as $\frac{2}{3}$ by using welded steel fabrication.

Steel may be placed as required—to meet functional requirements exactly. The design is not restricted by foundry requirements.

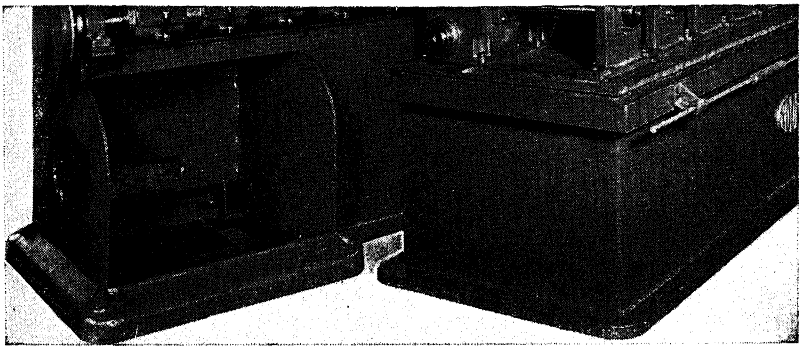


Fig. 477. Base of a cold rolled forming machine showing two methods of approach. Left: A welded steel design which simulates the former cast iron construction. Sides and bottom are of one piece, brake-formed with cast steel inserts welded into the corners. Stiffeners are welded into the flange at intervals. Right: The welded steel construction shown performs the same function yet its stream lined design, employing shear-cut and flame-cut plate costs materially less than the design which is made to look like cast construction.

Labor Costs are Lower.—Roundabout casting procedures are eliminated. Machining operations are minimized. Wasted man-hours due to casting defects are eliminated. Special machines can be produced with only slight modifications of the standard design, saving time and money. With shielded arc welding and today's highly efficient fabrication methods, production is faster.

Welding Reduces Fixed Charges.—Instead of purchasing parts from an outside source, they are made in the same shop. This work reduces overhead costs and thereby results in additional profit on *all* production.

Inventory Charges are Minimized.—Inventory for welding is approximately 10% of that required for casting. The standard steel parts used for welding can be purchased on short notice from any steel mill or jobber. *New design developments do not obsolete stocked material.*

Allows Freedom in Designing.—Steel, welded, permits an easy, quick, economical method of meeting the functional requirements, and results in a freedom of design not easily approached by other methods. A combination of steel castings and welded rolled steel (see Fig. 475) is sometimes used where the economic factors of the particular shop or installation so indicate. This freedom in designing results in most efficient utilization of the metal. Service requirements are adequately and economically met.

METHODS OF DESIGN

Introduction.—Design should start from the functional or service requirements of the machine to be designed. One of the first things to be considered is the loading and the resultant stresses on various parts. The material used must meet certain load conditions. These

are prime or simple load conditions, such as tension, compression, shear, torsion, bending. In machines these exist generally, in combinations rather than any one single type.

In addition to the type of load, the method of loading should be considered, as the rate of application of loading. This may vary from a dead load, an example of which is the weight of a beam . . . to a slowly applied load . . . to a more rapidly applied load . . . and finally a suddenly applied or impact load.

The frequency of loading also is important. It varies from a very few applications over a long period to a great number of applications in a very short time. Reciprocating parts are in the latter class, called fatigue or endurance loading.

It is evident that stress distribution must be given careful consideration because, if a section is stressed beyond its limit, regardless of how small it may be or whether it be in tension or fatigue, failure will occur. The intensity of the stress, and its kind, or class, are governed by the size and shape of the part and the amount and class of the loading. Good stress distribution uses material to advantage, thus reducing costs.

Ductility of the metal may be of great importance. This is the ability of the metal to change its shape or adjust to load conditions, thus resulting in a better stress distribution.

It is well to break down the major problem into the units and elements previously mentioned.

Design and Construction of a machine may be considered from three view points:

Preparation of the parts.

Welding.

Final or finishing operations.

As an example of a study in accordance with the above outline, joints will be discussed under each of these headings.

Preparation.—The preparation of the parts may be relatively simple (see Page 28), involving beveling or scarfing of the plate. Or it may involve cutting to shape and size or, perhaps, forming such as required in the construction of the bases shown in Fig. 477.

A single vee butt joint, for given plate thickness, requires about twice the amount of weld or deposited metal that a double vee joint requires. However, the machining is slightly more expensive on the double vee and it is necessary to weld from both sides, requiring the turning of the part. Both joints are equally efficient (if properly made) but one will be lower in cost than the other, depending on design and shop facilities.

It is interesting to note that a plate one inch thick (2′-0″ x 1′-0″) costs less if made of two plates 1′-0″ x 1′-0″, one inch thick, welded together, than to cast a 2′-0″ x 1′-0″, one-inch plate. This relatively simple example emphasizes the low cost of welded fabrication.

This discussion of joints can be continued, including single U, double U, tee joints, etc. These, too, may be considered in line with above, and the lowest cost joint determined.

Welding.—This is the primary operation in the making of joints. It is to be noted, however, that the size of the welder (see Page 218) and the size of the electrode (see Page 214) have considerable effect on cost . . . that the fewer the number of passes, the less the distortion (see Page 97). Naturally, welding costs go up in proportion to the amount of metal deposited (see joint discussion above). Flat welding is less costly than vertical or overhead welding, and can be produced at a higher rate of speed (see Page 154-167).

The joint must be accessible. The comfort of the operator should be considered. All of these have a very direct bearing on the cost of depositing metal or, in other words, the making of the joint.

Final or Finishing Operations.—The preparation and welding have a definite effect on the final or finishing operations. These final operations may involve just cleaning (note the need for ready accessibility to cut cleaning costs), followed by painting, or they may consist of more elaborate processes, such as sand-blasting, stress-relieving and heat treatments. They are dependent upon the type of the product, service requirements and loading. And, while in some cases they might be considered as part of welding, it is well to view them separately and inter-relations studied, thereby resulting in the maximum cost reduction for welded fabrication.

Rolled Steel—Can Be Used Efficiently—Comparison to Cast Iron.—Following is a specific example showing the utilization of materials, and their relative economy and efficiency of performance. A very simple case—that of a beam with a concentrated load at the mid-point—is used to illustrate a method and to keep the problem from becoming complicated and involved. Most machine tools are subjected to bending, usually combined with other types of loading.

The problem is to outline a method of design to change a simple beam from cast iron to steel. Note that this is not an academic discussion but is the result of a study where this particular problem was actually involved.

As in most cases of machinery, deflection is of great importance, it is here used as the outstanding criterion of design.

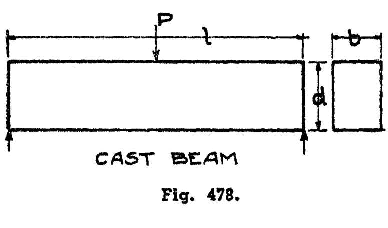


Fig. 478.

The complete formula for deflection for a beam loaded as shown in Fig. 478 is

$$D = \frac{Pl^3}{48EI} \quad \frac{+5}{384} \quad \frac{Wl^3}{EI}$$

where P = Concentrated load in pounds
l = Span of beam in inches

W = Total weight of beams in pounds
E = Coefficient of elasticity—pounds per square inch
I = Moment of inertia in inches^4
D = Deflection in inches

$\frac{Pl^3}{48EI}$ is the deflection caused by the concentrated load.

$\frac{5}{384}\frac{Wl^3}{EI}$ is the deflection caused by the distributed load or the weight of the beam itself.

Usually this may be disregarded because the deflection caused by the weight of the beam is relatively small in comparison to that caused by the concentrated load. For example a rectangular beam of cast iron 3″ x 10″ and 10′ x 0″ long with a concentrated load of 8,000 lbs. at the center, has a deflection due to this load of .096″ and the deflection due to the weight is .007″. In designing from cast iron to steel, the weight of the steel beam is less than that of cast iron and consequently the deflection in steel, due to the weight of the beam, is less than the corresponding deflection for the cast iron beam. The steel design will, therefore, be conservative and the deflection of the steel beam will be less than that of the cast iron beam if a simplified form is used, as the following:

$$D = \frac{Pl^3}{48EI}$$

A rectangular beam (Fig. 478) is used because it is simple insofar as the calculations of the moments of inertia are concerned.

Cast Beam

The deflection of the steel beam is to be the same as the cast beam. That is

$$D = \frac{Pl^3}{48E_{ci}I_{ci}} = \frac{Pl^3}{48E_sI_s}$$

from which $E_{ci}I_{ci} = E_sI_s$

$$I_s = \frac{bd^3}{12} \times \frac{E_{ci}}{E_s}$$

Note:
Subscript $_{ci}$ refers to cast iron; s, to steel
b = width of beam
d = depth of beam

$$I_{ci} = \frac{bd^3}{12}$$

Since $E_{ci} = 12{,}000{,}000$

$E_s = 30{,}000{,}000$

$$12{,}000{,}000 \times \frac{bd^3}{12} = 30{,}000{,}000 \times I_s$$

$$\frac{.4bd^3}{12} = I_s$$

Steel Beam

This is a reduction in weight of 60% as dimension "b" for the steel beam is .4 that of the cast iron beam. See Fig. 479. Note that this concerns the moment of inertia, and does not take into account warping of the plate as a web member. This characteristic will be considered later.

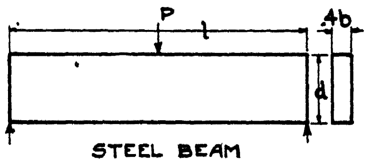


Fig. 479.

Consider the moment of inertia and its effect on design (comparing cast iron and steel). The general equation for resisting moment:

$$M = \frac{SI}{x}$$

where M = Bending moment in inch pounds (Resisting)
S = Stress in pounds per square inch (remote fibre)
I = Moment of inertia in inches^4
x = Distance from neutral axis to the most remote fibre in inches

The subscript "t" denotes tension and "c" denotes compression. Then:

$$M = \frac{S_t I}{x_t} = \frac{S_c I}{x_c}$$

The moment of inertia is the same on both sides of the equation. It follows from this that the ratio of unit stresses of tension to compression is equal to the ratio of the respective distances from the neutral axis or—

$$\frac{S_t}{S_c} = \frac{x_t}{x_c}$$

For cast iron the unit stress is assumed as 3,750 lbs. per square inch in tension and 22,500 lbs. per square inch for compression. Note that other figures may be used but these will not alter the conclusions. The ratio of distances to the extreme fibres is 1 to 6. In the same way, steel at 13,750 lbs. per square inch for both tension and compression the ratio is 1 to 1. The simplicity of design in steel is obvious.

In this discussion the section modulus $\frac{I}{x}$ is not definitely considered but rather the moment of inertia, which is part of the section modulus. The values of I and x depend upon the distribution of

metal and must be considered separately. If this statement seems unusual it should be remembered that the section modulus as given in structural hand books is for a definite rolled shape. In welded design the shape may be varied easily. This is one of the big advantages of welding—the placing of metal where it is most effective. This characteristic of welding is most important and should be borne in mind throughout this discussion. Otherwise designs would consist merely in the selection of standard shapes from catalogs.

It has been shown previously that for the deflection of a steel beam to be the same as a cast iron beam, the moment of inertia of a steel beam is .4 the moment of inertia of a cast iron beam. If the steel is stressed to the limit of the allowable working stress, the factors M, S and I are known.

$M = \frac{SI}{x}$ Therefore x is fixed. This factor x is one-half the depth of the steel beam. If the dimensions of the space available are such that a depth greater than 2x may be utilized, then x can be increased, resulting in a lighter section. Note this is an advantage obtained by use of high tensile steels. If x and S be increased then I may be obtained with materially less weight and consequently lower cost. A thin section costs less to weld than a thicker section and the material cost therefore is reduced both for base metal and weld metal.

I and x involve mechanical dimensions of the beam and buckling of the web should be considered. In most cases this is not a factor.

To show how the value of I and x may influence the design, consider cast iron and steel as two design materials and some definite figures. This comparison may be carried forward for any kind of materials and the figures given show the application to a specific case.

Assume unit stresses of 3,750 lbs. per square inch tension and 22,500 lbs. per square inch compression for cast iron. If these values are used to calculate a beam, the tension member will be very wide and the compression member very small. For example, a beam 10″ deep, a web ½″ thick, upper flange 1″ wide and ½″ thick. The lower flange will be approximately 20½″ wide and 2½″ thick. Such a shape is out of reason for production, both as a design application and a cast proposition. Therefore the theoretical design of the cast iron beam must be compromised with the production possibilities. The dimensions of the theoretical beam may be changed considerably by increasing the allowable stress for tension, but even then a non-symmetrical cast iron beam will result. Such a shape may not be practical from a cast standpoint.

Casting limitations are governing factors in determining the shape of the cast iron beam. The pattern must be of such design that it may be taken in and out of sand without disturbing the mould. For cast iron beams of other depths than this, the same relative high ratio of lower to upper flange is maintained due to the relatively high ratio of compression to tension working stresses.

The ratios which have been considered may be varied by changing the characteristics of the gray iron used for casting. The limitations imposed by the casting still exist due to its inherent characteristics as to tension and compression stresses.

This is not true of welded steel construction where it is possible to work every member to the desired limit and there are no difficult pattern considerations limiting the designer.

This is shown somewhat more definitely by the following.

In general, there will be space limitations of say 6″ wide and 10″ deep. Metal at a distance from the neutral axis is more effective for stiffness and weight reduction than metal at the neutral axis.

Assume that a web ½″ thick and an upper flange ½″ thick and a lower flange 1″ thick represent good foundry practice. The lower flange, being in tension, will require the larger area and it is necessary to go to the limit of available space or a width of 6″.

The question may be raised as to the reason for using a 1″ lower flange thickness but calculations show that for a thicker lower flange the increase of the moment of inertia or stiffness is below the proportional increase of the mass of metal or weight. This is illustrated by the sections 1 to 6, Table I, on Page 394. Note the change in moment of inertia, change in unit compression stress and the change in the maximum bending moment.

Cost is based partially on weight, and if the maximum bending moment in inch pounds is divided by the weight of the section in pounds per foot, the result is inch pounds per pound of material per lineal foot, which is a measure of efficiency of design. It will be noted that there is a considerable variation in this value. Definite sections give definite maximum bending moments. These sections may be selected on the basis of inch pounds per pound of material per lineal foot, but they must also be selected on the basis of the amount of the maximum bending moment.

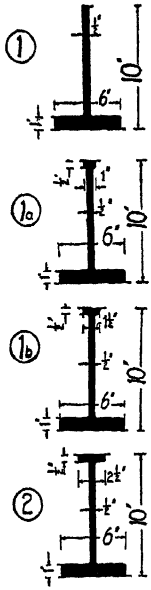
Table II shows for different ratios of thicknesses the ratios of the moment of inertia. Section 1 has been selected as the unit upon which comparisons are made with the other sections.

By reference to Tables I and II, Page 394, interesting comparisons of the sections shown with these tables can be made.

Moment of Inertia.—Comparison of Sections 1 and 1b on the basis of the unit tension of 3,750 lbs. per square inch, shows that increasing the width in the ratio 1:3, that is the area of the upper flange three times, a 25% stiffness is gained and the deflection is reduced; whereas increasing the depth of the lower flange at the same ratio, the area of the lower flange Sections 3 and 5 being increased three times, there is a gain of only 15% in stiffness, although relatively more area and consequently more mass is added by increasing the lower flange.

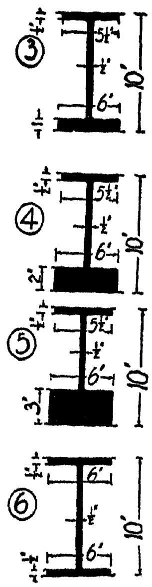
Bending Moment.—The bending moment is a measure of the capacity of the beam. As the bending moment and stresses are proportional to the respective areas, the bending moment increases with the area of the governing stress which, in the case of cast iron, is tension. Thus an increase of the area for the tension member will increase the bending moment to a greater extent than an increase in the compression member. By increasing the width of the upper flange three times, a gain of 13% is effected for the bending moment.

TABLE I



Section	Moment of Inertia I	Distance of Neut. Axis Xt	Xc	Stresses lbs./sq.in. Ten.	Comp.	Max. Bending Moment	Weight of Section per lin. ft.	Inch lbs. / lb.
1	96	2.64	7.36	3750	10400	136000	32.6	4150
1a	108	2.80	7.20	3750	9650	144500	33.6	4300
1b	120	2.94	7.06	3750	9000	153000	34.7	4410
2	142	3.26	6.74	3750	7750	163000	35.6	4560
3	197	4.01	5.99	3750	5600	184000	40.0	4600
4	221	3.26	6.74	3750	7750	254000	57.5	4410
5	227	3.08	6.92	3750	9100	277000	74.5	3746
6	166	5.00	5.00	3750	3750	125000	32.5	3850

TABLE II



Section	Ratio of Width Upper Flange	R of I	R of M	R of Wt.	R of in. lbs./lb.
1	1	1	1	1	1
1a	2	1.125	1.07	1.03	1.04
1b	3	1.25	1.13	1.07	1.06
2	5	1.48	1.20	1.09	1.10
3	11	2.05	1.35	1.23	1.11
Section	**Ratio of Depth Lower Flange**	**R of I**	**R of M**	**R of Wt.**	**R of in. lbs./lb.**
3	1	1	1	1	1
4	2	1.12	1.38	1.44	0.96
5	3	1.15	1.51	1.87	0.82
Section	**Ratio of A_c/A_t**	**R of I**	**R of M**	**R of Wt.**	**R of in. lbs./lb.**
1	1 : 24	1	1	1	1
2	1 : 4.7	1.48	1.20	1.09	1.10
3	1 : 2.18	2.05	1.35	1.23	1.11
4	1 : 4.36	2.30	1.87	1.76	1.06
5	1 : 6.55	2.36	2.04	2.30	0.90

By increasing the thickness of the lower flange three times, there is a gain of 51% for the bending moment.

From these figures the reader may make his own comparisons, indicating the limitations. The tension or compression or both can be varied, but it should be remembered to keep them within decent design limits. The reader, then, for his own specific problem, can discover just what its limits are.

Weight.—Certain characteristics are obtained as the area of the section is changed. Therefore, variation of the cost logically follows. Sections have been divided into groups which will be evident by looking at the tabulation given on Page 394. This may be illustrated by noting that when the area of the upper flange is increased three times the weight is increased only 7%. If the area of the lower flange is increased three times, there is an increase in weight of 87%.

It has been shown that for the same proportional increase of tensional area, there is a gain of 51% for the bending moment. This gain is obtained at an increased weight of 87%. Thus the utilization of material is not good.

Utilization of Material.—The real measure of a design is the utilization of the material. Reference to the first group of sections, 1 to 3 inclusive. Page 394, shows that with a constant lower flange and an increase in the upper flange of 1:2:3:5:11 there is an increase in utilization of material at the ratio of 1:1.04:1.06:1.10:1.11.

The second groups of sections, 3 to 5 inclusive, Page 394, shows that where the upper flange is constant and the depth of the lower flange increases at the ratio of 1:2:3, there is a decrease of utilization in the ratio of 1:.96:.82. Comparing the sections 2 and 4 there is about an equal ratio of the flange area. The increase of the flange width of section 2, which means increasing the area of the upper flange five times, shows an increase of 48% in stiffness with a 10% increase in utilization. Whereas the increase of the flange thickness, section 4, which is increasing the larger area of the lower flange of section 3 only two times, shows only 25% increase in stiffness with a 50% decrease in utilization. This demonstrates very clearly that the economical design is obtained by an increase of the width of the flange and not by the thickness.

Increasing the width of the upper flange or the compression section is preferable to the increase of the thickness of the lower flange. The increase in utilization, which is a measure of cost, is lower than the increase in stiffness, due to a reduction of compression stress. This is obtained at the expense of weight, which means a cost of material.

Such a section is relatively thin for cast iron and a beam with such a section is not particularly desirable from a casting viewpoint.

Example of How a Standard Rolled Steel Shape and a Built-up Shape Compare to a Cast Iron Beam.—Rolled steel shapes are produced in standard sizes. There may or may not be a standard size which meets the same requirements of the cast iron beam discussed previously. However, by the use of arc welding a special shape may be built up of rolled steel plates to meet these requirements. Thus

the designer is not limited to the selection of standard shapes. The requirements must be analyzed to determine whether a standard shape or a built-up shape is more practicable. A typical analysis follows:

$$D = \frac{Pl^3}{48EI}$$

$$M = \frac{SI}{x}$$

$$\text{or } M \frac{S_t I}{x_t}$$

$$= \frac{S_c I}{x_c}$$

The ultimate tensile stress of ordinary cast iron tension is 22,500 lbs. per square inch. The ultimate tensile stress of mild steel is 55,000 lbs. per square inch (figures are quoted from Marks Mechanical Engineers Hand Book).

In the tabulation just discussed, the maximum working stress for cast iron in tension is assumed at 3,750 lbs. per square inch, which is a safety factor of 6. Using the usual factor for steel gives 13,750 lbs. per square inch. Substituting these values in the equation above—

Since $I_s = .4I_{ci}$

$$\frac{3750 I_{ci}}{x_{ci}} = \frac{13750 \times .4I_c}{x_s}$$

or

$$x_s = \frac{5500 x_{ci}}{3750} = 1.47 x_{ci}$$

As previously mentioned, the ratio of stress in steel, tension to compression is 1 to 1, the section therefore is symmetrical. Again taking the available depth as 10″ and the width as 6″:

or

$$\frac{2x_s = 10}{x_s = 5}$$

With this value and the moment of inertia of steel section as a minimum and equal to .4 of the moment of inertia of cast iron section:

$$\frac{3750 I_{ci}}{x_{ci}} = \frac{S_s \times .4I_{ci}}{5}$$

$$\frac{3750}{x_{ci}} = \frac{S_s \times .4}{5}$$

$$\frac{3750 \times 5}{.4} = S_s \times x_{ci}$$

$$46875 = S_s \times x_{ci}$$

Reference to section 3, Page 394, x_{ci} is 4.01. Therefore, the unit stress of a 10″ theoretical steel beam having a moment of inertia of .4

the moment of inertia of the cast iron section 3, would be 11,650 lbs. per square inch. Using the other equation and the limiting value of stresses and calculating x_s:

$$x_s = 1.47 \times 4.01$$
$$= 5.9$$

The depth of the steel beam would, therefore, be 11.8″ exceeding the allowable space limits.

This shows that for a given bending moment and fixed unit stress, the steel beam being symmetrical, its depth is determined or for a fixed depth the maximum stress which can be obtained is determined. If commercial I sections are considered there should be selected that section which has the minimum moment of inertia. Considering section 3, this minimum moment will be found to be $.4 \times 197 = 78.8$. The distance $x_s = 5.9$ and, therefore, to fulfill the same requirements as a cast iron beam, it is necessary to find a rolled section with a minimum moment of inertia of 78.8 and a minimum section modulus of $78.8/5.9 = 13.3$, and a depth of 10″.

The section modulus has been used because that is easily calculated from the data available and it is given in the handbook. This has been used as a convenience and short-cut to obtain section wanted.

Reference to a structural steel handbook will show that the nearest section is a standard 9″ I-beam 21.8 lbs. per ft. with a moment of inertia of 84.9 and a section modulus of 18.9.

The maximum allowable depth is taken as 10″ and a 10″ I selected, which has a weight of 25.4 lbs. per lineal foot, a moment of inertia of 122 and a section of modulus of 24.4. This commercial 10″ section with its higher values will show a lesser stress, 9,700 lbs. per square inch, than the above discussed theoretical section of 10″ with its 11,650 lbs. per square inch. These rolled commercial sections thus limit the use of the material to the best advantage. Later will be discussed the built-up steel sections which may be fabricated by welding and which do not have the limitations imposed by the rolled sections.

In order to obtain a steel section with the same characteristics as the cast iron section 3 (see Page 394):

$$I_s = .4I_{ci}$$
$$= 78.8$$
$$x_s = 1.47x_t$$
$$= 5.9$$
$$\frac{M}{S_s} = \frac{I_s}{x_s}$$
$$= 13.3$$

If it is desired to maintain the stress of 13,750 lbs. per square inch, the ratio of $\frac{I}{x}$ which is equal to the ratio of $\frac{M}{S}$ is determined. This ratio is 13.3, which is the section modulus.

If it is desired to use the maximum allowable depth of 10″, x_s must equal 5. However, $x_s = 5.9$ according to the above equation.

Therefore there would be a lower value for the moment of inertia when $x_s = 5$. I_s would be 66.5 which is below the allowable minimum of 78.8, necessary to give a deflection not exceeding the specified amount. The loading, M, is given, as is also the maximum allowable space. These, with I_s determine the depth (2x) of the beam.

For a stress of 13,750 lbs. per sq. in., $x_s = 5.9$. The depth (2x) of this steel beam exceeds the available space. Since x = 5, the stress can be determined by the following equation:

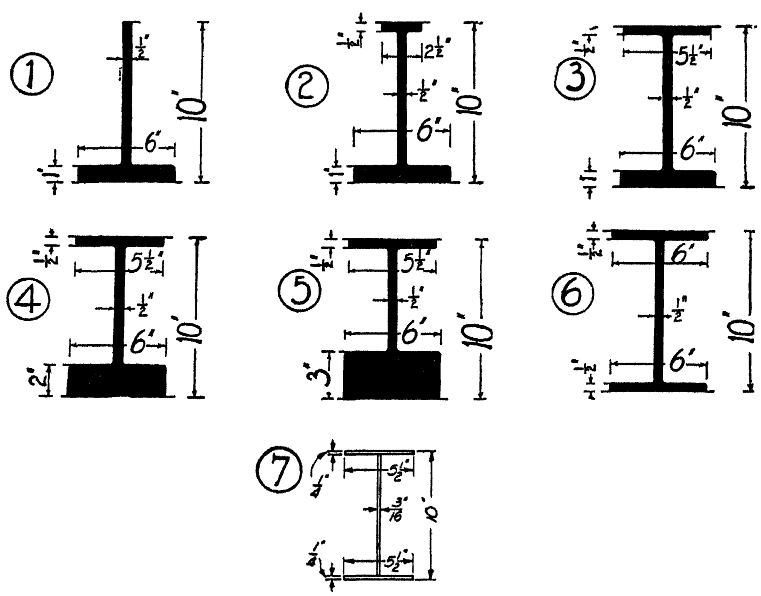
$$S_s = \frac{Mx_s}{I_s}$$

$$= \frac{184000 \times 5}{78.8}$$

$$= 11675$$

The maximum allowable working stress will not be reached if the depth of the steel beam is limited to that of the cast iron beam. However, the steel has a better stress ratio and a symmetrical section, the compression area of the steel being used to better advantage than the compression area of the cast iron section and this is very largely responsible for the weight reduction.

Steel could be used more efficiently for this particular problem in a built-up section than a standard shape. To determine just what this section will be, assume a theoretical section having two flanges 6″ wide 10″ apart. No web has been assumed in this theoretical section. Calculation shows that the flanges should be .2786″ thick. The weight of this theoretical section will then be 11.35 lbs. per foot, or 16,200 inch lbs. per pound. Sinch web buckling determines to a



Section	Max. Bending Moment in 1,000 inch lbs.	Weight Per Foot			Cost Per Foot		Inch Lbs. Per Lb.		Inch Lbs. Per 1c	
		C.I.	Steel	% = Steel C.I.	C.I. @ 6c lb.	Steel @ 3c lb.	C.I.	Steel	C.I.	Steel
1	136	32.6	17.5	54%	$1.96	$ .53	4150	7750	695	2560
2	163	35.6	18.4	51.5	2.14	.55	4560	8850	760	2950
3	184	40 0	21.8	54.5	2.40	.65	4600	8450	765	2830
4	254	57.5	25.0	43.5	3.45	.75	4410	10100	735	3375
5	277	74.5	25.0	33.5	4.47	.75	3746	11100	620	3700
6	125	32.5	25.5	78.5	1.95	.77	3850	4900	640	1620
7	184	40.0	15.4	38.5	2.40	.47	4600	11950	765	3980

certain degree the web thickness, a $\frac{3}{16}''$ web plate will be used. Inasmuch as there is no standard plate thickness of .2786, it is necessary to use a $\frac{1}{4}''$ plate for the flanges for the practical built-up section. However, the use of a $\frac{3}{16}$ inch web will increase the moment of inertia of the built-up section somewhat above 78.8, which is the required moment of inertia the section must possess to meet the requirements set up for the cast iron section. In fact, a $\frac{3}{16}''$ web increases the moment of inertia of the section to such an extent that the width of the flanges may be reduced from 6″ to $5\frac{1}{2}''$ without reducing the moment of inertia below 78.8. An I shape composed of three plates fused into a single unit by the electric arc, having a $5\frac{1}{2}''$ width and a 10″ depth, weighing only 15.4 lbs. per lineal foot, built-up shape as shown above as section 7.

Steel is superior to cast iron, even though the mechanical dimensions are such that the steel cannot be stressed to the maximum allowable stress.

The tabulation above shows the comparison of cast iron and steel and also gives a comparison of steel sections. A marked saving of weight is shown by the built-up section 7, as compared with section 3. The specific utilization of material, which means in this case the number of inch lbs. per one cent shows very clearly the advantages of steel. The tabulation shows that the best value for cast iron is 765 inch lbs. for one cent, whereas for steel we have as high as 3,980 inch lbs. for one cent. This is the advantage of the built-up steel section, which is obtained only by the welding process.

A striking example of the efficiency of a section of welded rolled steel over one of cast iron is the throat of a heavy duty punch press. This is shown graphically in Figs. 480 and 481. In Fig. 480 the steel section consists of a thick plate. In Fig. 481 a better utilization of material is shown by use of a built-up I section. The areas of the cast iron section, the heavy steel plate section and the built-up steel

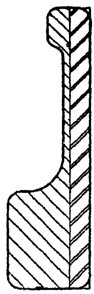


Fig. 480.

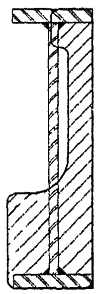


Fig. 481.

I section, as shown in these figures, are in the approximate ratios of 100:45:30, respectively. The shape and area of the sections were designed on the basis of equality of moment of inertia and the figures given in the following table. Since the throat of a press is subject to shock load, the factors of safety for this type of load are used.

Ultimate Values in lbs. per sq. in.	Material	Compression	Tension
	Cast Iron	90,000	22,500
	Rolled Steel	55,000	55,000

Safety Factors	Material	Load		
		Steady	Varying	Shock
	Cast Iron	6	10	20
	Rolled Steel	4	6	12

Working Values of Compression	Material	Load		
		Steady	Varying	Shock
	Cast Iron	15,000	9,000	4,500
	Rolled Steel	13,750	9,200	4,580

Working Values of Tension	Material	Load		
		Steady	Varying	Shock
	Cast Iron	3,750	2,250	1,125
	Rolled Steel	13,750	9,200	4,580

It may be argued that cast iron qualities may be improved; that the unit stresses may be changed; that other casting materials may be used. If this is done, the cost per pound is increased and the increased saving due to the weight reduction is largely offset.

In machine design when standard shapes can be utilized they will in general be low in cost, but their use may be limited due to the complications of loading.

The designer must take cognizance of the function of the machine. The steel should be laid out to meet the requirements without regard to the cast iron design. The designer should then determine whether standard steel shapes or built-up steel shapes will prove most efficient and economical. Built-up sections, made possible by arc welding, offer the designer a most efficient medium for meeting design requirements and provide lower production or machine operating cost or both.

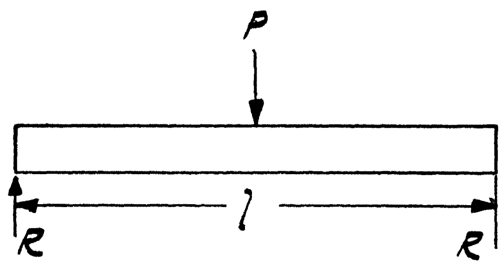
Deflection.—Deflection which is proportional to the bending moment and inversely proportional to the moment of inertia for any given material is a major factor in designing.

Only the mid-section of the beam has been discussed. It is evident, however, that there is a variation of conditions from the mid-section to the point of support.

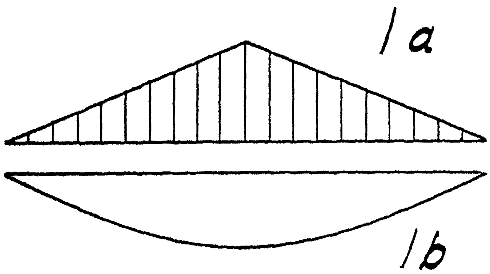
When a beam is simply supported, the bending moment and the deflection increase with the distance from support. If a beam is designed for a given deflection at the center the beam section required at the center, if continued throughout the beam, will make it heavier than necessary.

The depth of the beam calculated on the basis of the requirements at the center of the span, is not required at the points of support because the bending moment, and also the deflection, is zero at these points. Obviously the beam section cannot be reduced to zero.

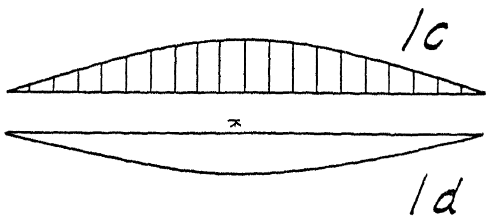
Rolled sections are evidently not the ideal shapes for this purpose because they are of uniform cross sections throughout. Built-up sections, fabricated by welding take advantage of all these conditions.



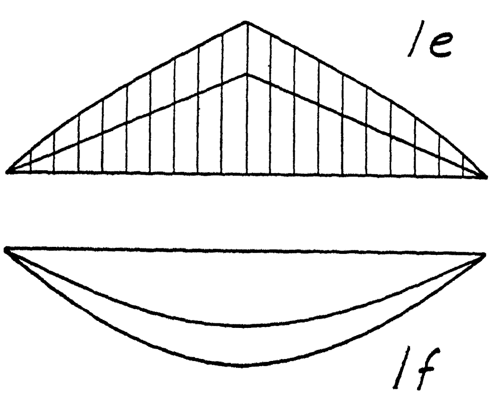
The accompanying drawing shows a beam with uniform cross section with reactions *R* and a load at the mid-point *P*. Calculating the moments for the various sections and plotting these moments as ordinates, the diagram *1a* is obtained. In a similar manner the depth



of the beam required for the concentrated load only is plotted, diagram *1b*. For a uniformly distributed load the moment may be plotted as shown in diagram *1c* and the depth required for the uniformly distributed load, including the weight of the beam, in diagram *1d*. These



two moments are added together in the diagram *1e*, the complete bending moment diagram for the conditions as assumed. For this complete moment diagram, there is a correspondingly complete diagram for the depth of the beam, which is shown in *1f*.



Shear.—Shear—the tendency for one section to slide past another—governs the size of the beam at the point of support.

External shear is the algebraic sum of the forces on one side only of the section. Shear will be expressed by ordinates drawn to scale at the sections of the beam under consideration.

Then,

$V =$ Total Shear. $S =$ Shear Stress. $A =$ Area. $S = \dfrac{V}{A} = \dfrac{V}{bd}$

For a concentrated load P at the mid-section, this is:

At support: $V = R = \dfrac{P}{2}$

At mid-section: $V = R - P = -\dfrac{P}{2}$

d (depth) $= \dfrac{P}{2bS}$ for total length of beam.

For a uniform load, which includes the weight of the beam (W), shear is given by the following equation:

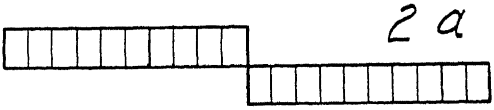
$V = R = \dfrac{W}{2}$ at support.

$V = R - \dfrac{W}{2} = 0$ at mid-section.

This is considered as immediately past the mid-section. Therefore:

d (depth) $= \dfrac{W}{2bS}$ at support. $d = 0$ at mid-section.

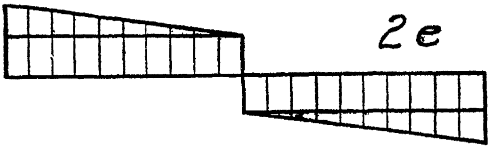
2 a

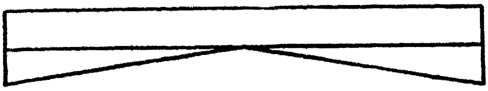


2 b

2 c

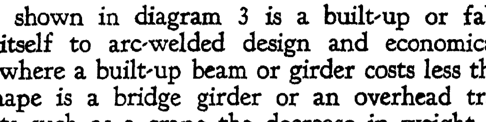
2 d





The shear due to the load *P* being constant between the supports; the depth would be uniform throughout the length *l*. The shear for the distributed load will be zero at the center increasing gradually to the points of support. The diagrams show these values graphically, namely: *2a* shows the shear and *2b* the beam depth for the concentrated load; *2c* the shear and *2d* the beam depth for distributed load. The combination of these two is illustrated by *2e* and the depth of the beam required is shown in *2f*.

In *1f* is shown the depth of the beam required for the bending moment and in *2f* the depth required for shear. These are combined in diagram, 3. It is evident from this diagram that a beam of uniform cross section is not the most economical type to use when weight is the governing factor. Also it is evident that the best design is that which follows the load requirements both as to shear and bending as indicated in diagram 3.



The beam shown in diagram 3 is a built-up or fabricated beam which lends itself to arc-welded design and economical fabrication. One example where a built-up beam or girder costs less than a standard commercial shape is a bridge girder or an overhead traveling crane. In mobile units such as a crane the decrease in weight by the use of built-up girders affects the cost of operation and the mobility of the unit.

It has been shown in the previous discussion that cast iron places more limitations on design than rolled steel, that the limitations placed on design by standard shapes of rolled steel can be removed by the use of arc welding to build up special shapes which will make the design more efficient. Thus by the use of arc welding, the few limitations placed upon the designer are those imposed by the metal itself. There are no further limitations imposed, such as the restrictions caused by available shapes or sections.

The designer can design and specify the size and shapes of the members to produce the units or parts of machine structure to make that machine more efficient, lower its cost of manufacture and improve its operating functions.

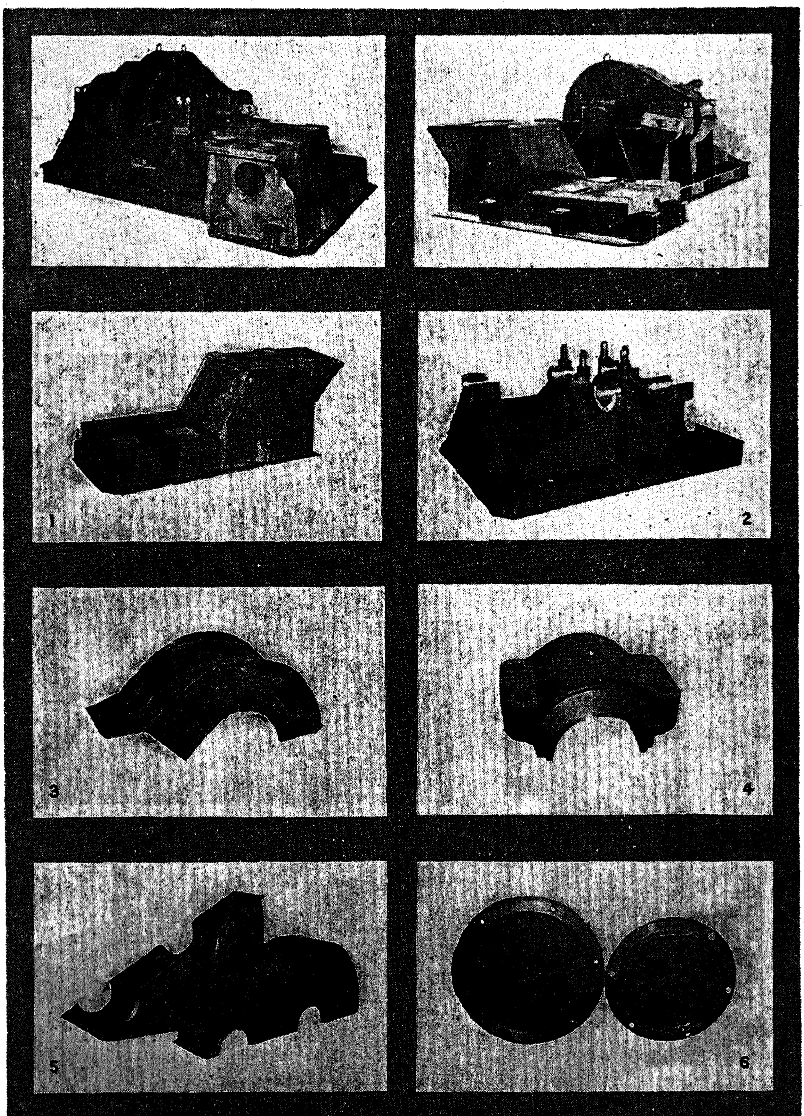


Fig. 482. Above: Two views of a tilting mechanism for a 150-ton tilting open hearth furnace. At first glance this would appear to be a fairly complicated design. However, it is merely an assembly of simple parts. These parts are shown below. (1) Base for the drive. (2) Base for speed reducing and operating mechanism. (3) Cover for tilting gear. (4) Cast steel bearing cap. (5) Speed reducer covers. (6) Bearing cap covers.

The Design Approach—One Part at a Time—A machine design is simply an assembly of main parts such as a base, frame, covers, containers, wheels and auxiliary parts such as levers, brackets, bosses and cams—regardless of how complicated it may seem. See Fig 482.

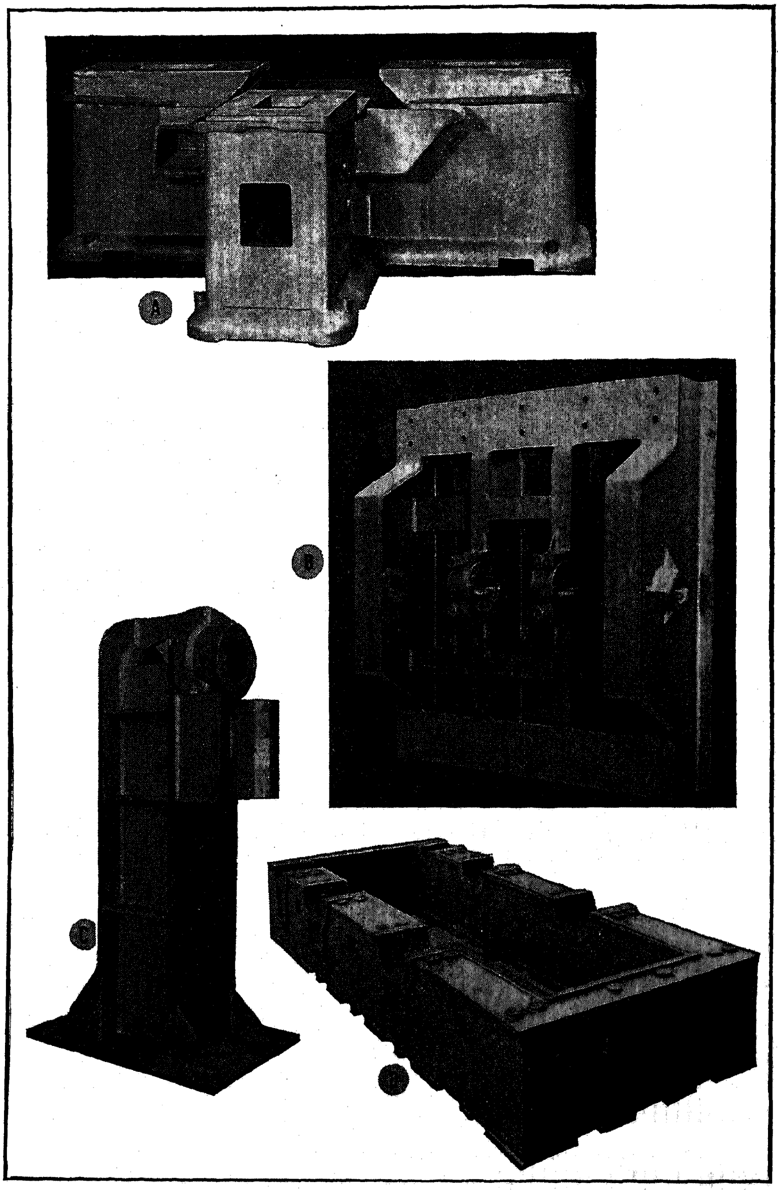


Fig. 483. Bases—(A) 4,000-lb. base for boring machine. (B) Shovel base. (C) Column for press. (D) 26-ton main bed for gear unit.

The simplest, most effective approach to welded machine design is to design *one part at a time* to meet the functional or service requirements of that part.

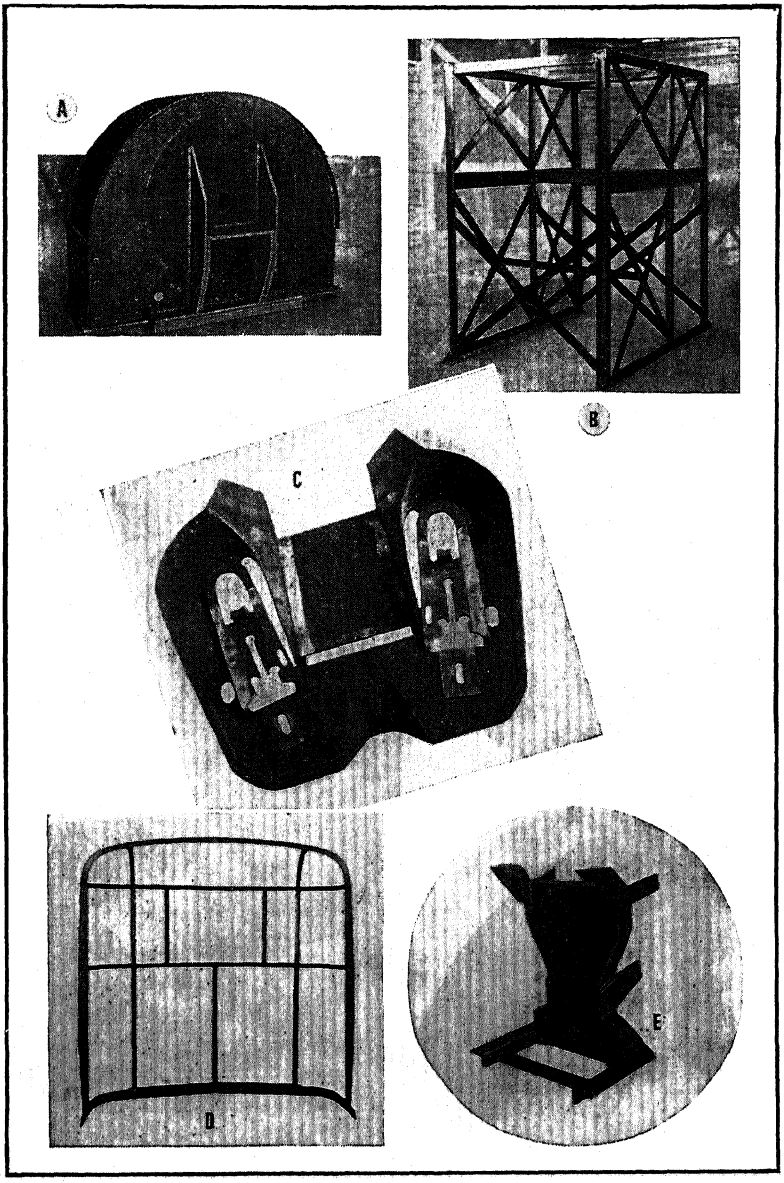


Fig. 484. Frames—(A) Pulverizer mill frame. (B) Framework for grain mill. (C) Gathering head for mining machine. (D) House trailer body frame section. (E) Rear post for road grader.

Classification of Units of Design.—The various parts of a machine may be grouped into the following main classifications, each of which has a variety of applications which determine its specific design.

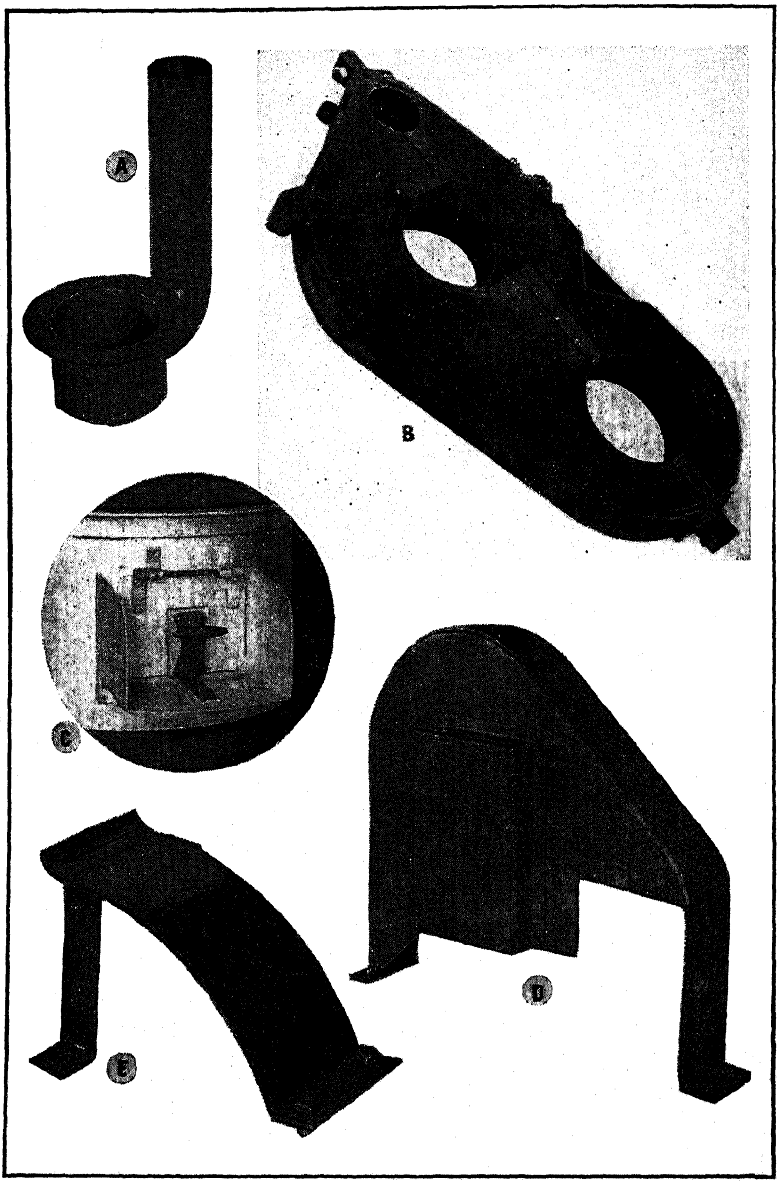


Fig. 485. Covers—(A) Air cleaner hood for crawler shovel engine. (B) Gear-case for mining locomotive. (C) Door for vegetable peeler. (D) Belt guard for compressor. (E) Sheave guard for crawler shovel.

1. Bases or frames.
2. Covers.
3. Containers.
4. Wheels.
5. Auxiliary parts.

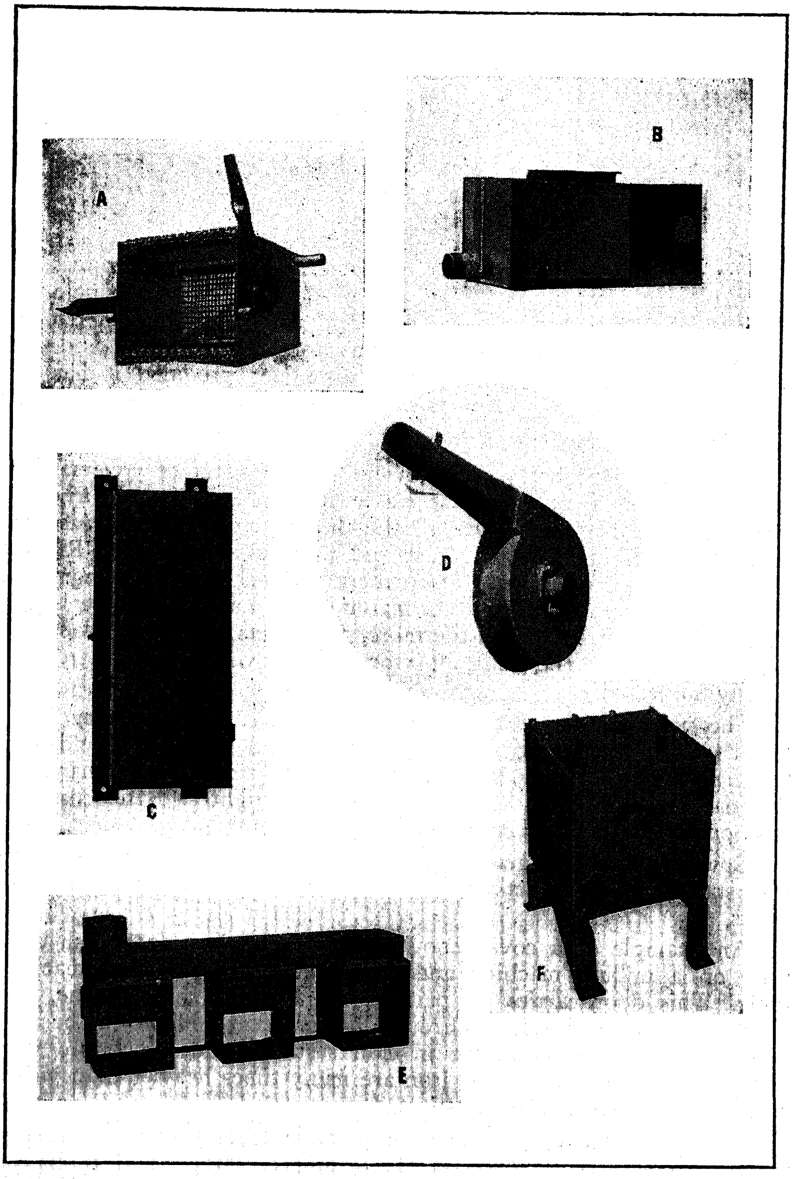


Fig. 486. Containers—(A) Basket for metal degreasing machine. (B) Discharge box for vegetable peeler. (C) Gasoline tank for power shovel. (D) Ice slinger discharge. (E) Grain mill grader spouts. (F) Sump tank for power shovel.

Following is a discussion of these units.

Bases.—These units of support are used in some form for practically every machine design. Often they are of the bedplate type. Sometimes they are in the form of a frame which serves as the support and housing for other parts. Typical bases and frames are shown in Figs. 483 and 484.

Covers.—This classification includes:

Gear Guards
Doors
Pulley Housings
Dust Covers
Lids, etc.

The purpose of covers on any machine is either to protect the internal mechanism from damage from the outside or to shield the moving parts so that they themselves will not be a source of danger. Usually covers are not subjected to any considerable stress, and consequently the lightest cover is the best cover provided it has the requisite stiffness. Examples are illustrated in Fig. 485. See also Part VIII (Machine Parts).

Gear guards probably are the widest used form of covers. The former method of making these was either by casting or by riveting steel. Cast gear guards have all the disadvantages of any cast-iron product which include high cost and unnecessary weight. Riveted gear guards, while utilizing less expensive steel, require flanging or flange angles, so that the cost to manufacture may possibly be higher than that of a casting. Furthermore, the rivets have a tendency to work loose under the constant vibration to which gear guards are usually subjected.

The construction of arc welded gear guards is simplicity itself. Sheet or plate is cut to the proper shape and the edges welded so that the entire part is an integral piece of steel. Gear guards of this nature may be made dust tight and oil tight and the cost is a fraction of that for other methods.

Covers other than gear guards can be made in the same manner. Use standard steel sheet or formed plate if necessary and weld all joints.

An example of a cover known to everyone is a door such as is used on a milling machine and very frequently on other machine tools. This door carries no part of the load on the machine, and is only subject to breakage through being struck. However, because cast iron is extremely brittle in thin sections, and which are very difficult to cast, doors of cast iron are many times heavier than would be required if steel were substituted.

Doors of this nature can be easily made from flat stock stiffened where necessary by welding on ribs or angles. Hinges and knobs can likewise be welded on and the cost would be less than for any other style of construction.

Containers.—The classification containers is extremely broad and includes:

Tanks of every description	Tumbling barrels
Boilers	Vats
Hoppers	Revolving driers
Drums	Dump cars
Bins	Clamshell buckets
Chutes	Annealing pots, etc.
Mixing chambers	Pipe and piping systems

For examples, see Fig. 486 and Part VIII (Machine Parts).

Tanks will be considered first because their use is more general than any of the other items in this classification. (See Pages 1042 to 1063.)

The first requisite of a tank is that it be tight. It must also have sufficient strength to withstand the internal pressure to which it may be subjected. In pressure tanks the plates and joints are in tension. In riveted construction, which was formerly the only method of making tanks, the strength in tension of a riveted joint is always less than the strength of the plates joined. This is because the plates are weakened at the joint by the rivet holes. To obtain the necessary strength it is therefore necessary to provide for this weakness at the joints. Since the efficiency of the usual riveted joint varies from 45% to 75%, the increase in the thickness of the plates to provide for this is considerable and represents a large part of the cost of any tank.

In arc-welded construction the joints are made as strong as the plates joined. It is not necessary to make the plates thicker throughout their length to provide for the requisite strength at the joint.

Here, then, is one great saving by using arc welding in place of riveting. Furthermore, the actual cost of making the welded joint is less than that for making a riveted joint.

In tank work there is still another advantage. In riveted tanks the method of making tight joints is by caulking the metal along the edge of the plates, a makeshift at best and is also expensive. It is frequently necessary to recaulk after the tank has been in service a short time. Arc-welded tanks are tight because the plates are solidly joined making the tank actually a single piece of steel. In addition, a welded tank resists corrosion better than a riveted tank, and avoids leaks around rusted rivets.

Containers other than tanks can also be made by arc welding cheaper than by riveting or casting. Examples include conveyor buckets, concrete mixing drums and many others.

Wheels.—Included in this classification are all types of wheels, gears, pulleys and sheaves. In many cases their manufacture can be made more economical by the use of arc welding. Ample evidence of this is presented by the increasing number of welded products of the above classification which are now applied to machinery and other mechanical equipment.

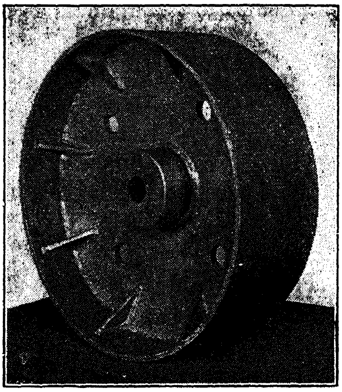


Fig. 487. Heavy duty pulley of arc-welded steel construction.

The pulley, Fig. 487, is made up of steel plate with the exception of the hub which is of round bar stock drilled for shafting. Note that the small triangular pieces of plate welded in place as shown transmit the load from the wide face of the pulley to its web.

Gears and gear blanks are shown in Figs. 488 and 489. They are similar in that the rims and hubs are constructed alike. The hubs are sections of round bar stock drilled for shaft. The rims are plate or flat bar stock formed into rings with abutting ends arc welded. The web construction is different for each of the gears or blanks shown. See also the gear blanks in Fig. 476.

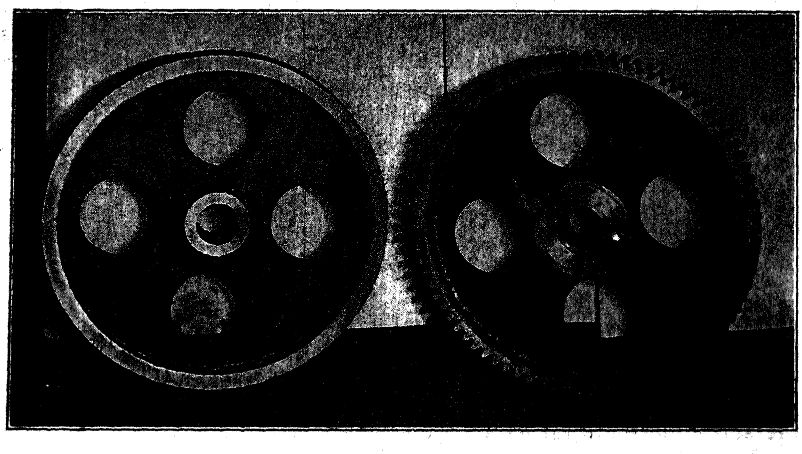


Fig. 488. Arc-welded gear blank and finished gear of 26-in. O.D.

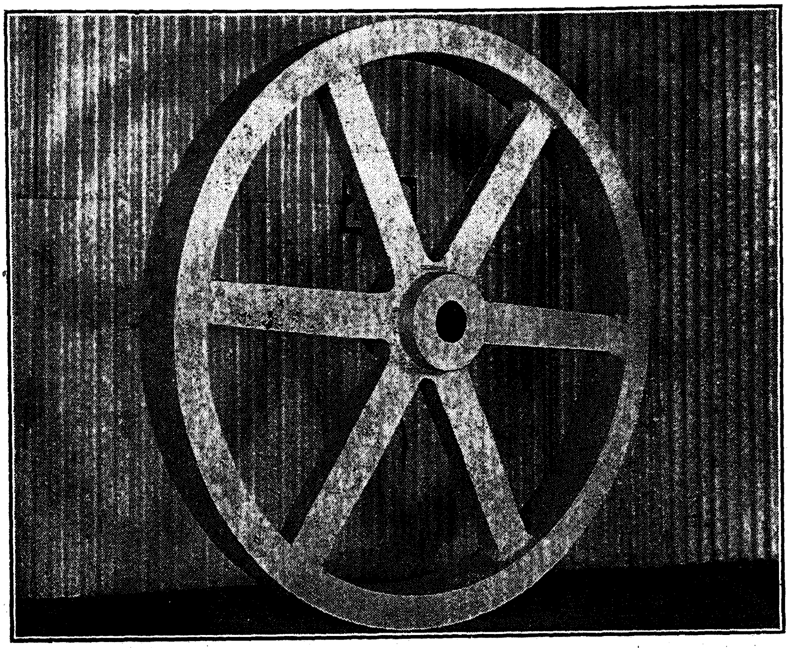


Fig. 489. Three pieces of rolled steel were fused into one by the electric arc to form this six-spoke gear blank.

Three Methods of Design.—There are three methods of design, namely: (1) The approximate or direct replacement of steel for cast iron. This involves the use of steel in place of cast iron, sections being proportioned to the dimensions of the original casting. (2) The conventional method wherein some account is taken of load or service conditions and the members, joints, etc., proportioned to that load, using established values for loading. (3) The precise method wherein unit stresses are carefully figured and the design worked out in detail.

Each of these methods is used in its proper place.

DIRECT REPLACEMENT METHOD OF DESIGN

Any approximate method of producing a satisfactory design will not necessarily obtain the most efficient use of material or lowest production cost. With these limitations in mind, the application of this approximate method may be made.

It is not always possible to know the loading, but the dimensions of the casting to be replaced are known. It is therefore possible to work from these dimensions and lay out the welded steel construction.

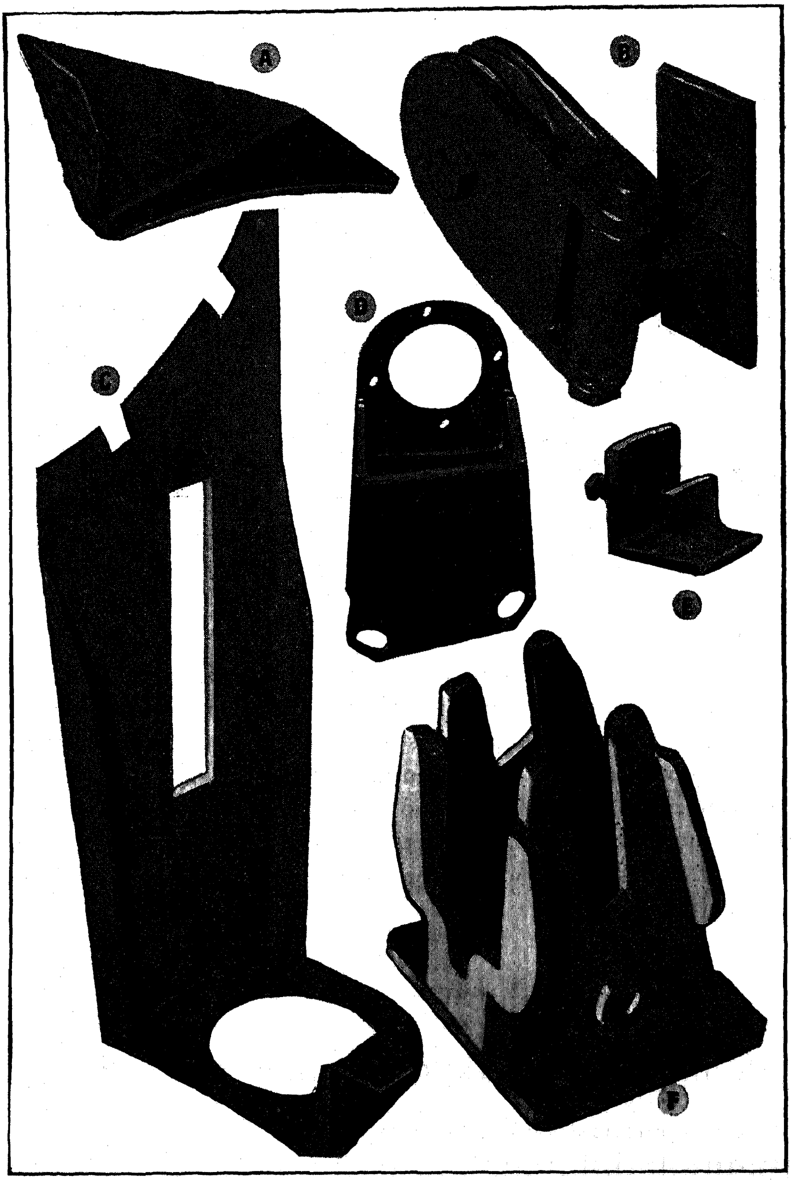


Fig. 490. Brackets—(A) Engine step for crawler shovel. (B) Tagline fair leader and sheave for shovel. (C) Engine air cleaner support. (D) Oil pump bracket. (E) Gauge clamp. (F) Take-up rack for shovel chain control.

In most machines, deflection is a very important item, generally the governing one. The steel design must therefore have a deflection no greater than that of the cast iron. Assuming that one section of

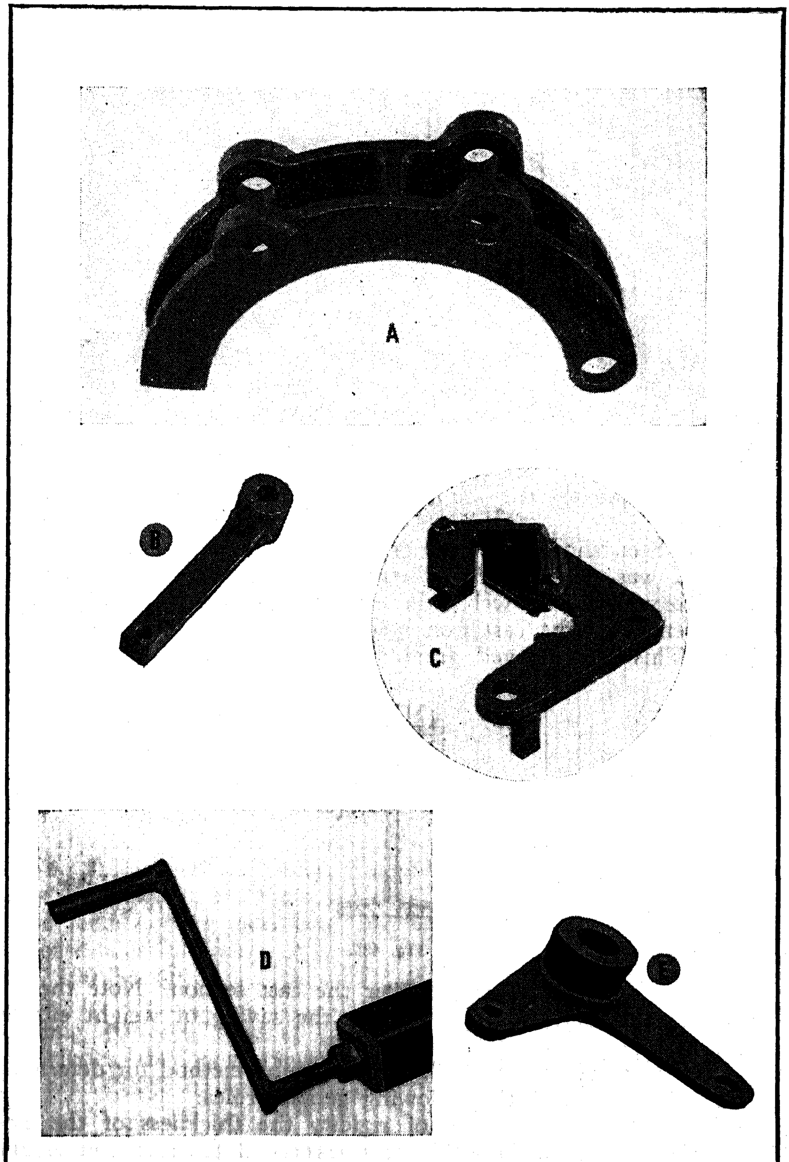


Fig. 491. Levers—(A) Chain tightener for mining machine. (B) Lever for mining locomotive. (C) Lever for slabbing machine. (D) Pressure block crank for bending machine. (E) Machine tool lever.

the old casting is an approximate rectangle as shown in Fig. 492, then the steel section for the same deflection will be as shown in Fig. 493 (see Page 390).

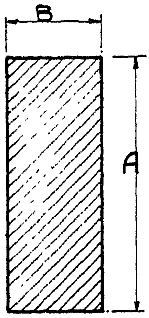


Fig. 492.

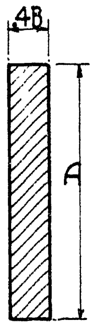


Fig. 493.

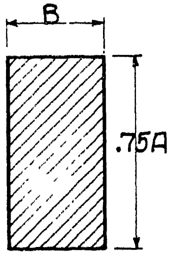


Fig. 494.

For the same depth the steel width should be not less than four-tenths of the width of the cast iron section. If necessary to maintain the width, then the depth for steel will be three-fourth that of the cast iron, Fig. 494. In one case a 60 per cent saving in weight and in the other only 25 per cent.

Quite frequently the section for cast iron looks something like an I-beam.

It has been shown that the greatest weight saving resulted when the depth was not reduced. Therefore the depth will be kept the same. The width of the web and the thickness of the flange are reduced to four-tenths of the cast iron value, but the depth is the same as before. This is portrayed graphically in Fig. 495 where the steel

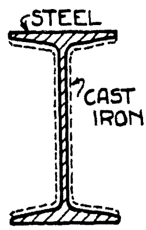


Fig. 495.

section has been superimposed over the cast section. Note the difference in thicknesses of the section, the saving of weight effected by use of steel.

A summary of the above "rule of thumb" method for determination of design evolves the following general rules:

(1) For the same degree of rigidity the thickness of the steel section should be 4/10 the thickness of the cast iron section, other dimensions of the steel to be the same as for cast iron.

(2) Where strength is the determining factor with rigidity a secondary factor, the thickness of the steel section should

be one-third the thickness of the cast iron section; other dimensions of the steel to be the same as for cast iron.

(3) Where strength is the determining factor and rigidity is unimportant, the thickness of the steel section should be ¼ the thickness of the cast iron section, other dimensions of the steel to be the same as for cast iron.

In these general rules the ratios of required thickness of steel to cast iron are based on the values of these materials as tabulated on Page 400, also on 30,000,000 pounds per square inch as coefficient of elasticity for steel and 12,000,000 pounds per square inch for cast iron.

Specific Examples—A Simple Support.—To illustrate the Direct Replacement Method of design, consider a simple base as shown in Fig. 496. Assume that this cast iron base is 18″ x 21″ x 15″ high, weighs 162 lbs., has a section thickness of ½″ and costs $9.22 (at 6 cents per lb.).

Here, both strength and stiffness are the determining factors. Hence, in designing for welding, follow Rule (1), Page 416.

First consider the replacement of the cast iron with standard structural shapes and rolled steel plate.

Due to the greater strength and stiffness of rolled steel the various members of the arc-welded bases may be ⅜″ in thickness instead of the ½″ section required for the cast iron base.

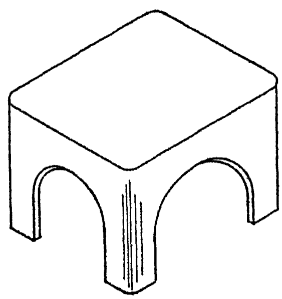


Fig. 496.

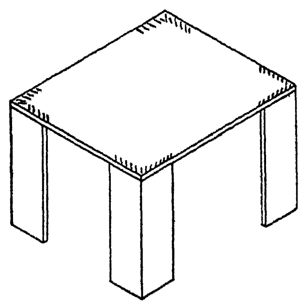


Fig. 497.

The arc-welded steel base, Fig. 497*, is composed of one 18″ x 21″ x ⅜″ plate for the top and four 5″ x 5″ x ⅜″ angles for the legs. These members are assembled and welded as shown. The cost of this base is as follows:

Steel, 100 lbs. @ 3¢	$3.00
Cutting to size	.10
Welding, 40″—⅜″ fillet @ 10¢ ft.	.33
(includes labor, power and electrodes)	
Overhead 200% of Labor	.86
Total cost of welded steel base, Fig. 497	**$4.29**

*In this discussion of Methods of Design drawings of welded parts are illustrative only, showing the assembly of component parts. Welding symbols such as are used for working drawings (see Page 44) are not shown.

An improvement of design and appearance of the arc-welded base may be obtained by the addition of an apron or rails connecting the top and legs as shown in Fig. 498. Thus nine members assembled and arc welded as shown form this base. The cost is as follows:

Steel, 111½ lbs. @ 3¢	$3.35
Cutting to size	.13
Welding, 90″—⅜″ fillet @ 10¢ ft.	.75
(includes labor, power and electrodes)	
Overhead 200% of Labor	1.76
Total cost of welded steel base, Fig. 498	$5.99

Compare the arc-welded steel base, Fig. 499 with the cast base, Fig. 496.

The welded steel base consists of three pieces of ⅜″ plate cut and formed as shown in Fig. 500. The assembly and location of welds are shown in Fig. 499. The cost of this base is as follows:

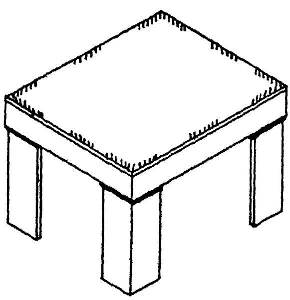


Fig. 498.

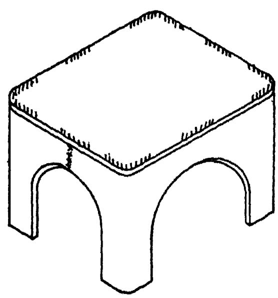


Fig. 499.

Steel, 88 lbs. @ 3¢ per lb. (less scrap)	$2.64
Cutting	.15
Forming	.08
Welding, including labor, power and electrodes.	
12″—¼″ butt weld @ 9¢ ft.	.09
48″—¼″ fillet weld @ 6¢ ft.	.24
Overhead 200% of Labor	.66
Total cost of welded steel base, Fig. 499	$3.86

It should be noted that all the designs for the steel bases are calculated on the physical characteristics of welds made by a shielded arc, with the most modern equipment. Welding costs are also computed on this basis. Welding costs will be somewhat higher when other equipment is used.

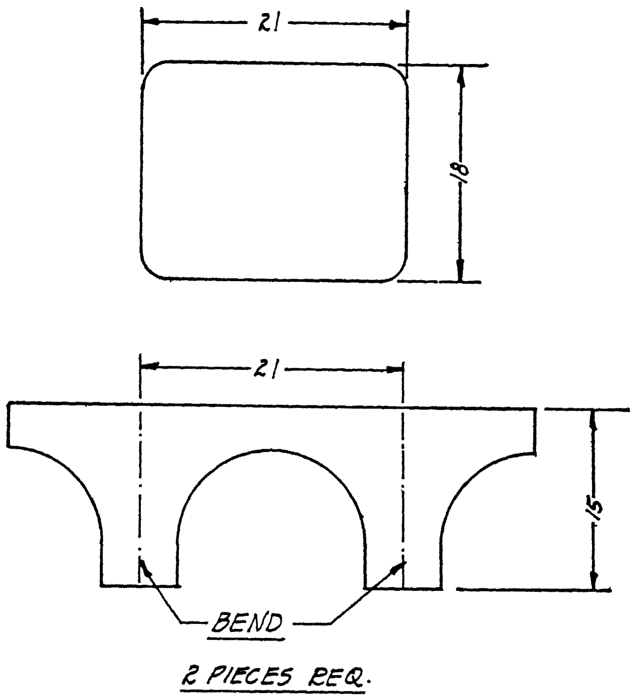


Fig. 500

A comparison of the total costs and weights of the cast base and the arc-welded steel bases shows from 33% to 57% cost reduction.

Description of Base	Cost	Weight
Cast Iron, Fig. 496	$9.72	162 lbs.
Arc-Welded Steel, Fig. 497	4.29	100 lbs.
Arc-Welded Steel, Fig. 498	5.99	111½ lbs.
Arc-Welded Steel, Fig. 499	3.86	88 lbs.

A Base.—Next, take for an example of Direct Replacement, the more involved base shown in Fig. 501. This particular cast iron part is approximately 55″ x 26″ x 20″ high, weighs 1350 lbs. and has main supporting members of ¾″ thickness. Here again both strength and stiffness (Rule 1) are the requirements.

In this case, ½-inch rolled steel would provide for greater strength and stiffness than the ¾-inch cast iron sections. (Equal strength and stiffness would dictate a 5/16-inch rolled steel section. However by using ½-inch material, superior service will be assured at a substantial saving in weight (33% reduction) and cost over the cast iron construction.)

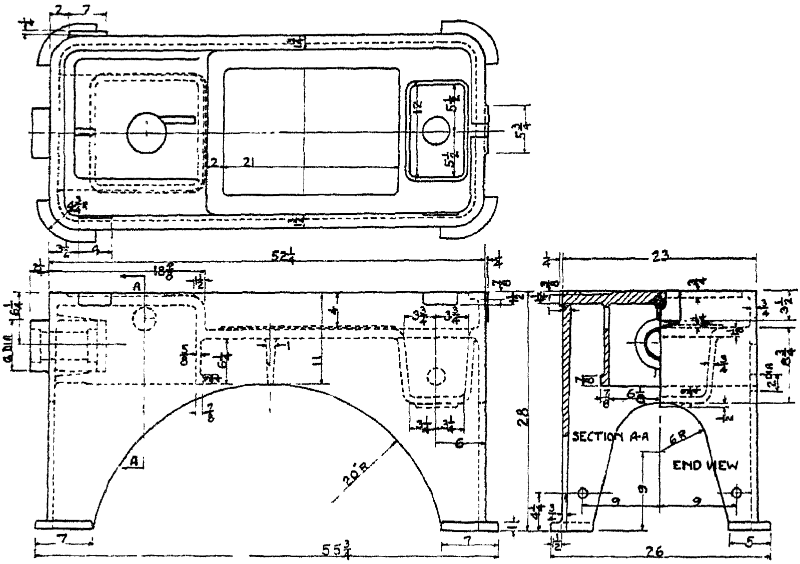


Fig. 501.

Instructions for the fabrication of this base can be conveyed to the shop in two ways. The simplest and quickest method would be to revise the casting drawing with yellow pencil notations as shown

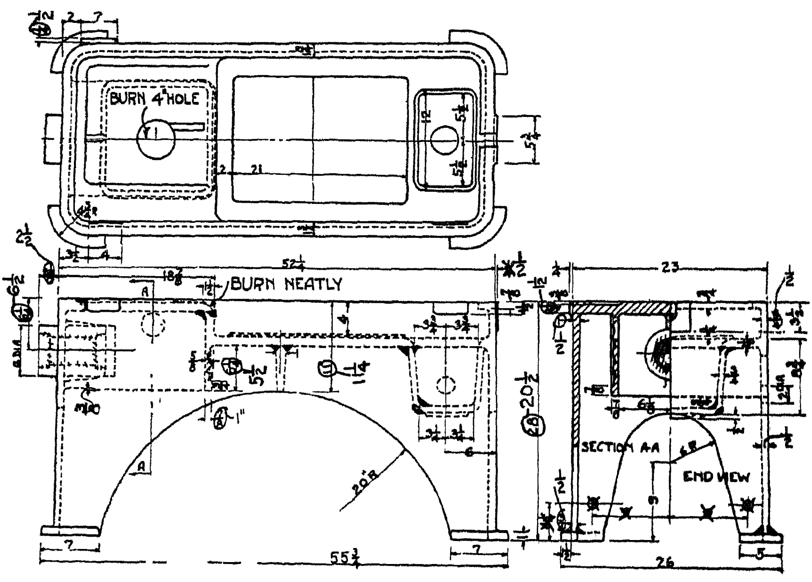


Fig. 502.

in Fig. 502. The second, more satisfactory way would be to make a new drawing with all sections drawn to scale for welded design and with minor refinements such as might be advisable in view of the use of rolled steel and welding. See Fig. 503.

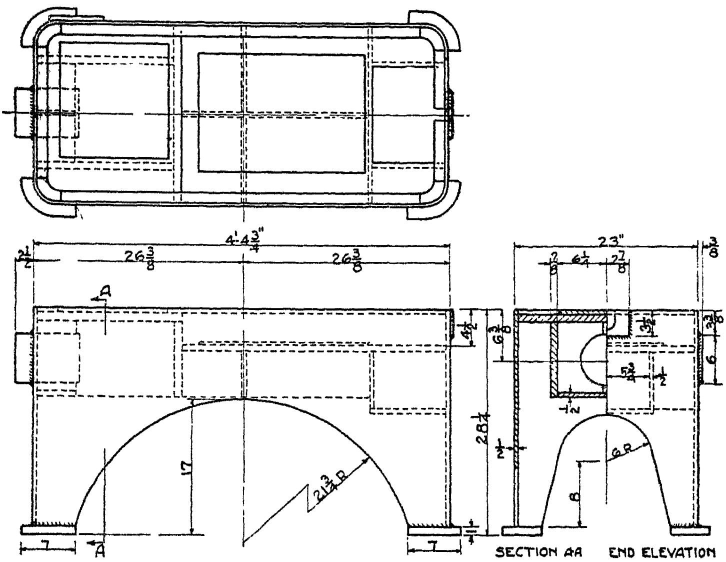


Fig. 503.

Press Frame.—This is an actual example of a fabricated steel press frame to replace a cast iron frame which broke in service. All overall dimensions had to be maintained so that it could be moved into place without changing other equipment and setup.

The original design, shown in Fig. 504, comprises solid cast iron members of the dimensions shown (main columns 6″ x 9″). Its weight was 4800 lbs.

Here, rigidity and strength are the determining factors. Hence, Rule (1), Page 416 applies.

The requirements of rigidity with maximum strength and savings in weight can be met to greatest advantage by the use of a fabricated box section to replace the solid cast iron members. Such rigid box sections are made possible by arc welded fabrication at low cost. The dimensions of the main column members can be increased sufficiently to permit this box construction with even greater strength and rigidity than the cast iron and at the same time to keep the floor mounting dimensions the same.

Cross-section of the cast iron members is 6″ x 12″ = 72 sq. inches.

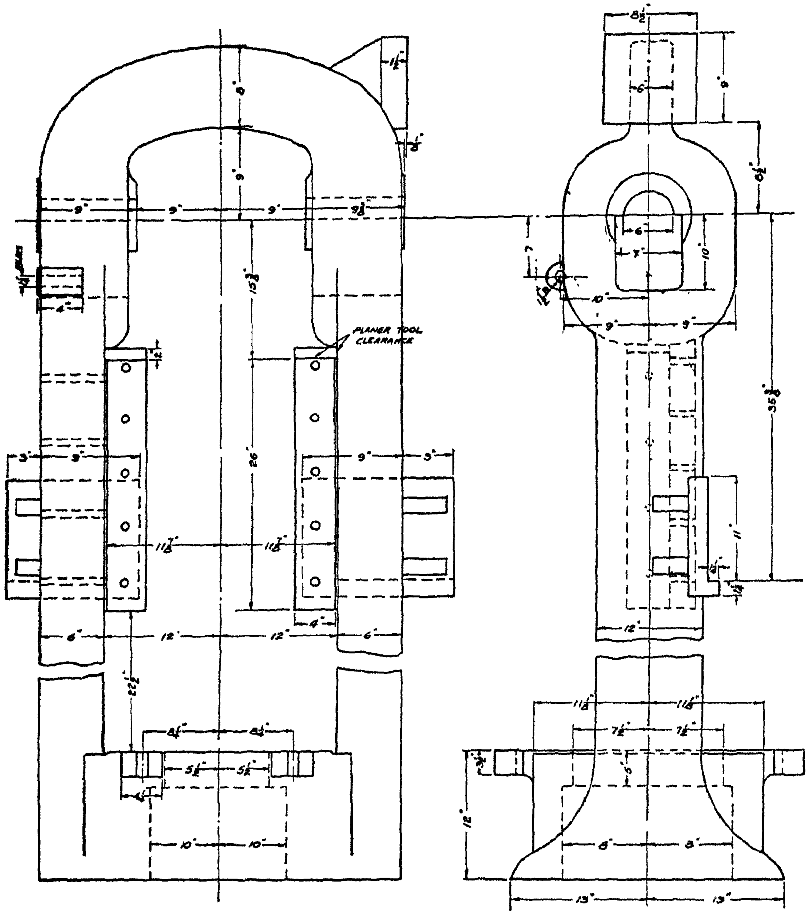


Fig. 504.

Hence, for rolled steel, a cross-section of .4 x 72 = 28.8 sq. in. is required. This can be secured by using a box section of 3/4" plate, built to the dimensions shown in Fig. 505. The minimum section of the fabricated columns is 6" x 14 3/4". The resultant area is approximately 31 sq. in. which more than meets the requirements. Additional strength and rigidity is provided by stiffeners welded on the inside of the box section as shown in Fig. 505.

Other sections and parts of this frame are replaced by steel in like manner.

CONVENTIONAL METHOD OF DESIGN

In this method, some account is taken of load or service conditions and the members, joints, etc., are proportioned to the requirements, using established values for loading. The following practical examples illustrate this method.

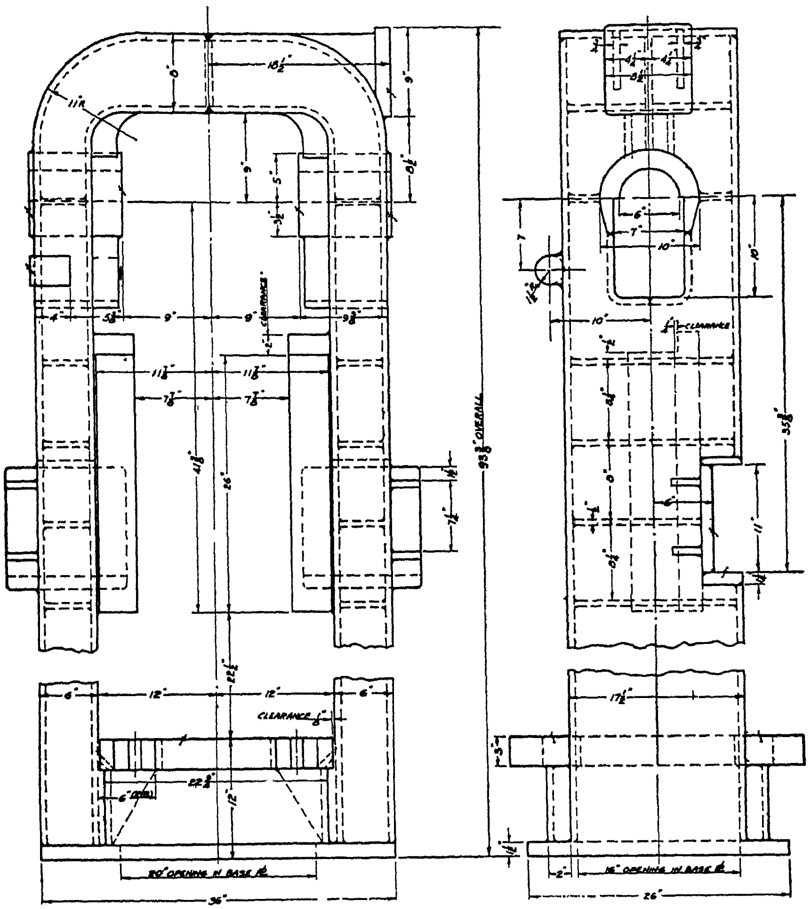


Fig. 505.

Line of Bedplates.—Most bedplates are of a type which has a self-contained load, such as a motor-driven pump or motor-generator set.

A study is first made of the floor plans of the bedplates being used. These plans may be grouped into three general classes:

(1) Symmetrical about two axes. (See Fig. 506).
(2) Symmetrical about one axis. (See Fig. 507).
(3) Not symmetrical. (See Fig. 508).

It is assumed that all three bases are the same height and about the same cross-section. They should be studied to see whether or not certain sections could be used interchangeably.

For example: Section A (Fig. 506) is the same shape as A in Figs. 507 and 508, and sections B of Figs. 507 and 508 are the same shape. If the bases are divided along the line as indicated, then all that would be needed to make any one of these bases or, in fact, any one of many kinds of bases, would be parts A and B. These can be as-

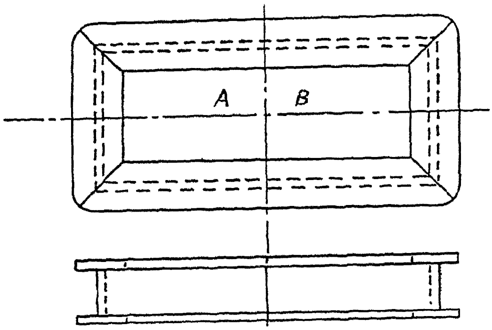


Fig. 506. Example of bedplate symmetrical about both horizontal axes.

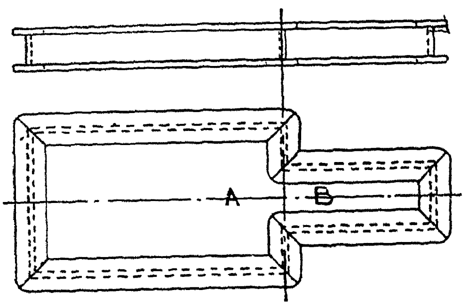


Fig. 507. Example of bedplate symmetrical about one horizontal axis only.

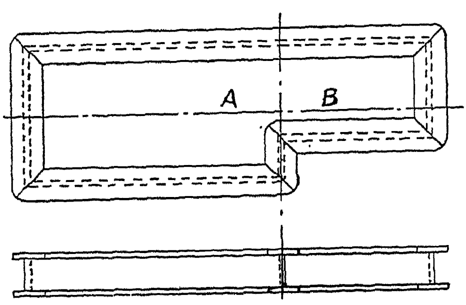


Fig. 508. Example of bedplate not symmetrical about either horizontal axis.

sembled in any desired combination resulting in A-A base, B-B base, or A-B base with any desired variation or difference in center lines. (See Fig. 522.)

Then the base should be studied in relation to the holding down bolts. These should be laid out accurately as to plan and then the largest base necessary should be sketched in roughly, and see whether or not the smallest plan would fit on to the largest plan to an advantage, assuming, of course, that the holding down bolts are in the center of a boss, which boss may be moved around to accommodate the required dimensions. All of this study indicates very clearly and definitely the flexibility of design made possible by welded fabrication. This reduces the number of stocked parts, resulting in lower inventory costs. Because of these advantages, this phase of the problem should be given a great deal of thought.

Next, study should be made of the relative heights of the support planes of the driving and driven units. In general, the distance A (Fig. 509) from the support plane to foundation is not of extreme importance, but the difference in elevation B of the two planes is important. A base for a motor driving a pump, for example, must have the difference in elevation between the point of support of the motor and the point of support of the pump made rather accurately, whereas the distance from the motor support to the foundation is not of prime importance. These differences should be studied. In a good many cases differences may be taken care of by devices similar to those shown in Figs. 583-586 or, in some cases just a machined plate will serve.

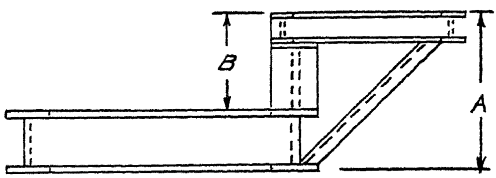


Fig. 509. Example of bedplate having two elevations.

After the general scheme has been laid out and the number of base sizes and dimensions have been generally set, consideration should then be given to the joining of the various parts.

The flexibility of this method, permitting quick delivery of standard or special bases, and the low cost, is most attractive.

Now having the size, shape and depth of base settled, methods of joining the parts determined and types of joints laid out, then the design can be started.

Design Procedure.—To illustrate how to design a simple bedplate, as shown in Fig. 506, for arc-welded steel construction, it is necessary that definite loads and limiting dimensions be assumed.

The loads are indicated in the accompanying diagram, Fig. 510. Approximate dimensions are shown in the preliminary plan, Fig. 511. The loads shown on diagram are for one side of the bedplate only and are for two machines (such as a pump and motor) weighing 1,000 lbs. each. After the loads have been determined the next step is

to lay out the location of the points of attachment, in plan, and also to check the overhang of machines involved so that the bedplate dimensions will be correct as to length and width insofar as clearance is concerned.

From the dimensions given in the load diagram, calculate the bending moments involved. One of the simplest ways to do this is to do it graphically. This is indicated in the sketch. Disregarding the weight of the beam, the bending moments are as follows.

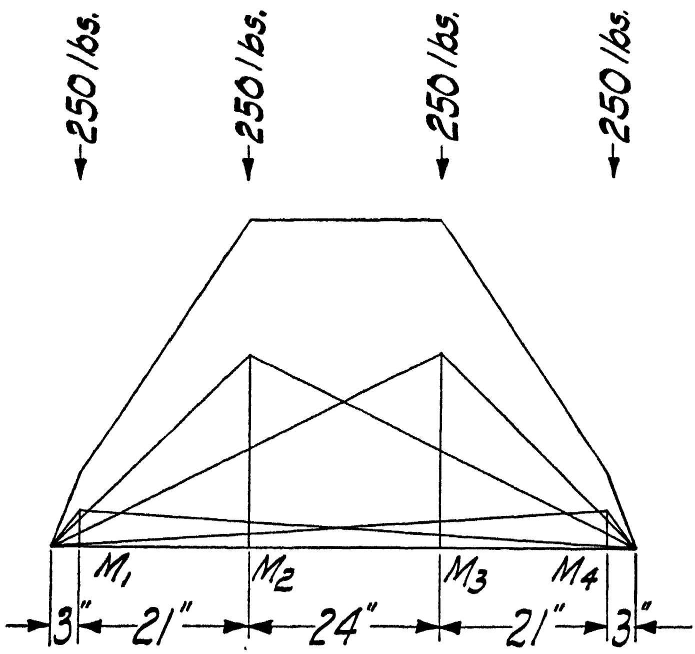


Fig. 510. Combined load and moment diagram for bedplate, Fig. 511.

The subscripts indicate the location of the moments involved:

$$M_1 = 3 \times 250 \times \frac{69}{72} = 718$$

$$M_2 = 24 \times 250 \times \frac{48}{72} = 4000$$

$$M_3 = 48 \times 250 \times \frac{24}{72} = 4000$$

$$M_4 = 69 \times 250 \times \frac{3}{72} = 718$$

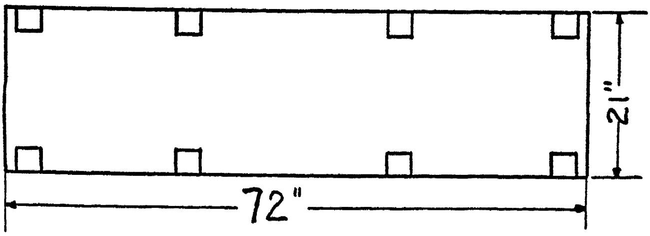


Fig. 511. Preliminary plan of bedplate.

Plot these bending moments to a suitable scale properly located on the load diagram. At the various points add them and plot a complete curve, which will give the total bending moment diagram. Then scale this maximum moment and it will be found that it is 6750 inch lbs. for this case. Use equation

$$M = \frac{SI}{x}$$

and use 13750 lbs. per sq. in. as the unit stress for the first determination of the section modulus. Calculate the section modulus from above equation.

$$6750 = 13750 \times \frac{I}{x}$$

$$\frac{I}{x} = .492$$

A reference to any structural handbook will show that a 3 x 3 x ¼ angle has a section modulus of .58, whereas a section modulus of only .492 is required.

$$6750 = S \times .58$$
$$S = 11650$$

Assuming the base is supported at ends only, the deflection under the given loading is less than $\frac{1}{16}''$ which, under the conditions assumed, is negligible. Therefore, since the stress will be below the assumed limitation and the deflection is negligible, this size angle will be satisfactory.

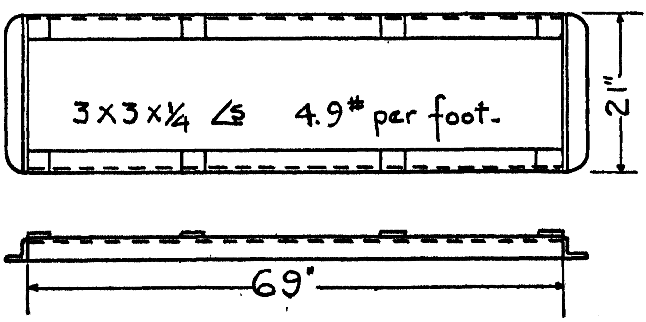


Fig. 512. Plan and elevation of bedplate.

Using angles, the bedplate is constructed as indicated in Fig. 512. Due to the location of the points of machine attachment as shown on drawing, the side members need only be 69″ in length. A 3 x 3 x 1/4 angle weighs 4.9 lbs. per foot. There is the total of 15 feet, made up as follows:

Ends	2 x 21″ =	42″
Sides	2 x 69″ =	138″
		180″ or 15 ft.

The weight is $4.9 \times 15 = 73.5$ lbs.

Calculation from a shear standpoint will show that one inch of 1/8″ fillet weld on each leg of the abutting angles is all that is necessary to use to make the joints strong enough to withstand the load conditions. However, a 1/4″ fillet weld is somewhat easier to make than a 1/8″ weld. In these joints it would perhaps be more practical to use 1/4″ fillet weld instead of 1/8″ fillet. This gives an extra factor of safety at little cost. Due to twisting action on the angles, the welds at each corner should be distributed partly at the toes and partly at the heels. Since the amount of welding in this case is so small, it would probably be best to put about 1/2″ to 3/4″ length at each point. The bedplate is assembled upside down, the joints being welded on the inside. The cutting of the corners as indicated is optional and is largely a matter of appearance. See Page 456 for sketches of this type of joint.

A similar example, but somewhat more complicated, is discussed in the following paragraphs.

Bedplate Symmetrical About Longitudinal Axis Only.—This type of bedplate may be such as is used for an engine driven generator (see Fig. 507).

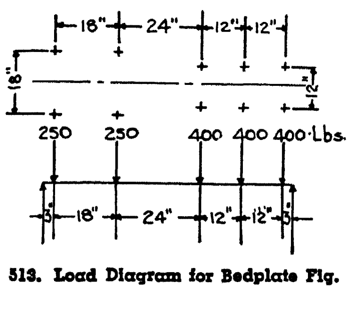


Fig. 513. Load Diagram for Bedplate Fig. 515.

The bedplate has a load as indicated in the load diagram, Fig. 513. From the load diagram, which shows the loads and their locations, the moment diagram, Fig. 514, is constructed in the same manner as has been outlined previously. The bending moments are as follows:

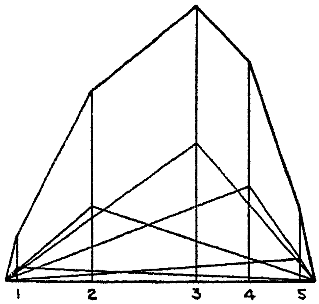


Fig. 514. Moment diagram for bedplate, Fig. 515.

$$M_1 = \frac{3}{72} \times 250 \times 69 = 718$$

$$M_2 = \frac{21}{72} \times 250 \times 51 = 3720$$

$$M_3 = \frac{45}{72} \times 400 \times 27 = 6750$$

$$M_4 = \frac{57}{72} \times 400 \times 15 = 4750$$

$$M_5 = \frac{69}{72} \times 400 \times 3 = 1150$$

These moments are laid out to a suitable scale and the maximum moment is determined, which is 13,494 inch pounds. From the mechanical considerations and following the scheme outlined for selection of members, it is determined that a 4″ x 3″ x $\frac{5}{16}$″ angle, weighing 7.2 pounds per foot, will be suitable. As the section modulus of this angle is 1.23, the unit stress in the most remote fibre is 10,800 pounds per square inch. This is calculated as outlined in previous pages. The general construction of the bedplate is shown in the drawing, Fig. 515. The bedplate is then constructed by using two side angles which are cut in the horizontal lengths and bent to conform to the dimensions required. Note that the heavy load end of the bedplate is supported by a cross angle which acts not only as a stiffener but also forms the joint in the side angles. In addition to this, holding down lugs are provided at this point. The end supports are of the usual angle type with corners rounded for the sake of appearance. Note also that only one size angle is used for the construction of this bedplate. This, of course, results in considerable economy.

The first step in the construction of the bedplate is to cut the angles to size. The 3-in. legs of the two angles forming the sides of the bedplate must be cut and the angles bent to shape as indicated. The bedplate is so designed that with the exception of the side hold-down lugs, it may be welded entirely from one side, eliminating all

unnecessary handling. In case of quantity production a very simple fixture is all that is necessary to facilitate assembly and welding. Use of fixture will thus lower production costs. (See Page 211.)

The load determines the size and length of weld required at each joint. In this case the total load per side is only 1700 lbs., therefore, a 1/4″ fillet weld, which has a safe tension and shear value of 2500 lbs. per lineal inch, is ample. The location of the welds is indicated on the drawing. Here again, on account of possible twisting action, the weld at each corner should be distributed part at heel and both toes. Calculations show 1″ of 1/4″ fillet ample, but due to this distribution perhaps 3/4″ at each of these points should be used. Fig. 554,

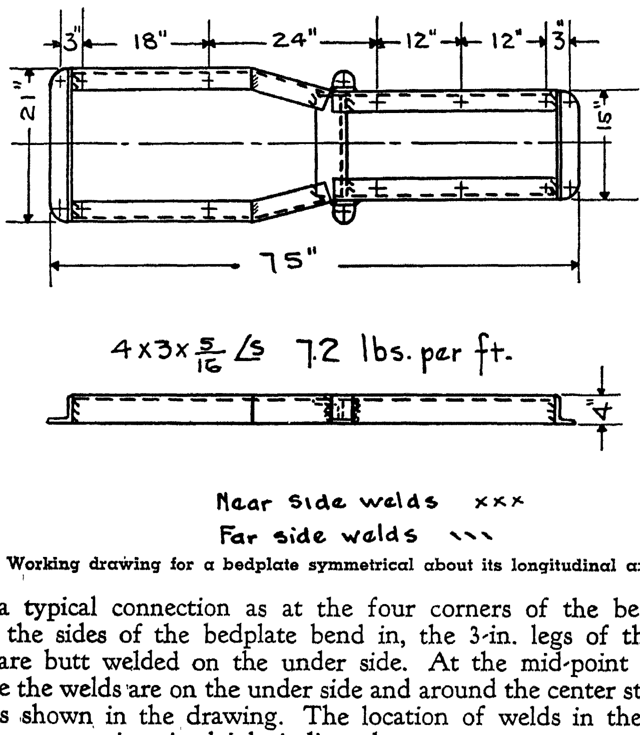


Fig. 515. Working drawing for a bedplate symmetrical about its longitudinal axis only.

shows a typical connection as at the four corners of the bedplate. Where the sides of the bedplate bend in, the 3-in. legs of the side angles are butt welded on the under side. At the mid-point of the bedplate the welds are on the under side and around the center stiffener angle as shown in the drawing. The location of welds in the hold-down lug connections is plainly indicated.

The deflection of this particular plate is well within the allowable limits governed by the loading conditions.

The list of material required for the arc-welded steel bedplate is as follows:

1 angle 4 x 3 x 5/16		1′-3″	long
1 angle	"	1′-9″	"
2 angles	"	5′-9 3/8″	"
1 angle	"	1′-2 1/4″	"
2 angles	"	0′-3″	"
Total lengths		16′-3″	

16 1/4 × 7.2 lbs. = 117 lbs. of steel.

The cost of the bedplate is estimated as follows:

117 lbs. of steel @ 3¢	$3.51
Cutting steel to size and bending	.57
Drilling and grinding	.50
Welding @ $1.00 per hr. including set-up time	.40
Electrodes and power consumed	.05
Overhead	1.15
Total Cost of Arc-Welded Steel Bedplate	$6.18

A cast iron bedplate of same dimensions and for same loading would weigh approximately 212 lbs., which @ 6¢ per lb. including the necessary drilling, grinding and machining, would cost $12.72 or about twice as much as the arc-welded steel bedplate.

Examples of Redesign.—The graceful curves, rounded corners and flowing lines of castings are obtained easily in arc-welded rolled steel construction, and generally at a materially reduced cost when designed properly. The following cast iron base, Fig. 516, offers an example of a typical base which can be duplicated for lower cost in arc-welded steel construction. The overall dimensions of the cast base are 45″ x 22″ x 6″ high. The larger end of the base is approximately 21″ x 22″ and the smaller end, 24″ x 14″. The section or thickness is ½″. The weight, 240 lbs. The cost, as estimated at 6 cents per lb., is $14.40.

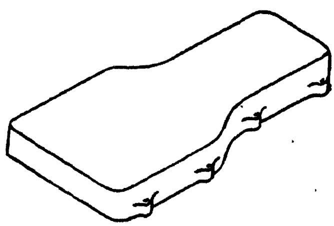


Fig. 516.

Due to the greater strength and stiffness of rolled steel, the various members of an arc-welded base may be ⅜″ thick instead of the ½″ section required for the cast iron base.

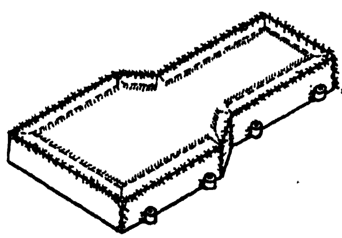


Fig. 517.

It may seem logical to design the arc-welded steel base as shown in Fig. 517. This design requires four 6″ x 3½″ x ⅜″ angles for the sides and a ⅜″ plate for the top of base. The horizontal legs of the angle

members are notched to permit bending to the required contour of the base outline. The four angle pieces are then assembled and welded as shown to form the sides of the base. The top plate is placed in position and welded to the angles as per Fig. 517. The bosses are merely pieces of drilled shafting stock welded to the sides of the base. The cost of this base is as follows:

Steel, 228 lbs. @ 3¢	$ 6.84
Cutting and Bending angles	.20
Cutting plate	.85
Welding, 16′—3/8″ weld @ 10¢ ft.	1.60
Overhead, 200% of labor	5.30
Total cost of welded steel base, Fig. 517	$14.79

The cost of the welded steel base, Fig. 517, proves the inefficiency of the design and therefore should be considered only *what not to do*.

The design, Fig. 518, offers a more practical solution. This design requires only 1/4″ plate cut for bending as shown in Fig. 519. To give the required rigidity to the bed, two stiffeners are incorporated into the assembly as shown. The appearance of this arc-welded steel base is comparable in every respect to the cast base, Fig. 516. The cost of the welded rolled steel base is as follows:

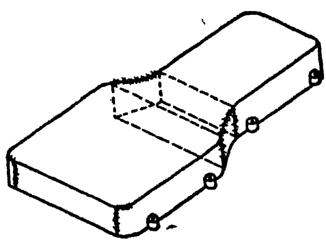


Fig. 518.

Steel, 155 lbs. @ 3¢	$4.65
Cutting	.49
Forming	.35
Welding, 6′ of weld @ 10¢ ft.	.60
Overhead, 200% of labor	2.88
Total cost of welded base, Fig. 518	$8.97

It should be noted that all the designs for the steel bases are calculated on the physical characteristics of welds made by a shielded arc with the most modern equipment. Welding costs are also computed on this basis. Welding costs will be somewhat higher when other equipment is used.

A comparison of the total costs and weights of the cast base and the arc-welded steel bases may be obtained from the following tabulation.

Note that arc-welded steel construction of the properly designed base of the type and size indicated saves approximately 38% of the cost of the cast base.

Description of Base	Cost	Weight
Cast Iron, Fig. 516	$14.40	240 lbs.
Arc-Welded Steel, Fig. 517	14.79	228 lbs.
Arc-Welded Steel, Fig. 518	8.97	155 lbs.

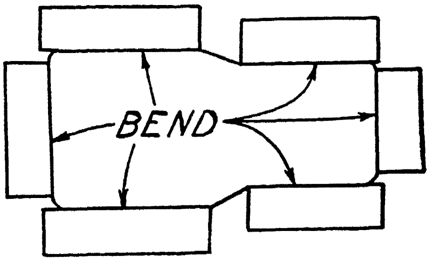


Fig. 519.

Unsymmetrical Bedplates.—Bedplates which are not symmetrical about either axis—for example, Fig. 520—may present some intriguing problems to the designer. The lack of symmetry makes the mechanical problem of the selection of the rolled steel parts to be used particularly unusual. However, the method of analysis is in general the same as for the usual symmetrical bedplate. First, all load conditions should be determined and load diagrams made. Particular attention should be paid to the kind of load which will be imposed on the bedplate.

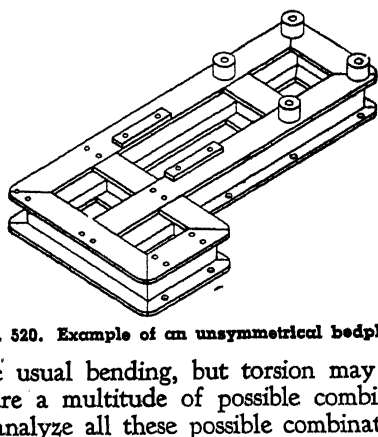


Fig. 520. Example of an unsymmetrical bedplate.

There will be the usual bending, but torsion may be combined with bending. There are a multitude of possible combinations of bending and torsion. To analyze all these possible combinations would require more space than may be allotted here. A brief general outline of the analysis may prove helpful.

After the loads are diagrammed, study should then be given to the mechanical layout. It may be well to divide the bedplate into several parts, depending upon load conditions. After determination of the principal part the required members of this part should be calculated on the basis that they will be unaffected by load conditions on other parts. This same procedure should be followed through for determining the members of the other parts of the bedplate. The members of each part should then be further calculated with consideration given to load conditions on one part affecting members in another part. The greater the number of combinations of load conditions the more intricate the analysis and determination of the proper size, shape and weight of the various members of the bedplate.

Comparison of Designs and Costs.—Arc welded steel construction proves exceptionally economical when applied to groups of bases which are almost identical in shape, but vary only in location of one center line. (See Page 424).

For example, a manufacturer of pumps and similar equipment might require 270 variations of such a base for his complete line. Assuming combination patterns and a possible ratio of 5 to 1, that is 5 bases made from one combination of patterns, this means that 270/5 or 54 patterns would have to be made. At an average cost of $250 per pattern, the investment in patterns would be $13,500. The charges for depreciation and storage on these patterns would be at least 10% or $1,350, which amount would purchase complete arc welding equipment.

A typical example of such a base is illustrated by the casting, Fig. 521. The units of this base measure 22″ x 14″ and 18″ x 18″ with overall depth of 4¼.″ The base weighs 275 lbs. The cost of the casting without machining, as estimated at 6 cents per lb., is $16.50.

The arc welded steel base, Fig. 522, is offered for comparison to the cast base. Units A and B have in common a bar member, C. The two units may be placed in innumerable positions, in relation to each

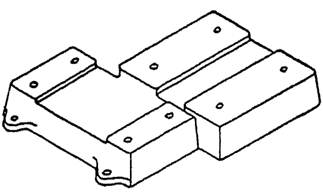


Fig. 521.

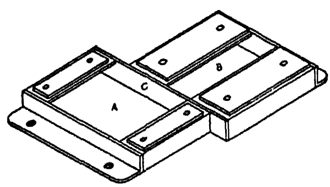


Fig. 522.

other, along member C. Thus by varying the length of C all possible combinations of A and B may be obtained to form any required base. Units A and B may be made up and carried as stock items.

Because the base height is 4¼″, angles having a 4″ leg should be used with this leg vertical. Boss plates should be ¼″ thick to bring the base to the required height. Boss plate dimensions for Unit A are 4″ x 13½″ x ¼″—for B, 5½″ x 17½″ x ¼″. These dimensions determine the size of the other leg of the angles required for framing

the two sides of each unit. For A, the sides should be 5″ x 4″ angles; for B, 6″ x 4″. The thickness of the angles to be determined by the loading of the base. If the casting has a section of ⅝″, the greater strength and rigidity of rolled steel allows the use of angles only ⅜″ thick. The end angles may be 4″ x 4″ x ⅜″. Bar C, the member common to both A and B, is 4″ x ⅜″.

The welds are all placed on the inside of the frame of base. This is easily accomplished by turning the base over to weld. The boss plates are welded all around from the top side of base. Welding all around the boss plates is not essential to sound construction, as a few intermittent welds properly placed will suffice; however, the appearance is improved by a continuous weld, but the cost is increased.

The cost of the arc-welded rolled steel base is as follows:

Steel, 127 lbs. @ 3¢	$3.81
Cutting	.10
Welding—6.3′ of ⅜″ fillet @ 10¢	.63
13.5′ of ¼″ lap @ 6¢	.81
Overhead, 200% of labor	3.08
Total cost of welded steel base	$8.43

It should be noted that the design for the steel base is calculated on the physical characteristics of welds made by a shielded arc with the most modern equipment. Welding costs are also computed on this basis. Welding costs will be somewhat higher when other methods are used.

A comparison of the total costs and weights of the cast base and the arc-welded steel base shows that arc-welded steel construction costs 49% less and weighs 53% less than the cast base.

Description of Base	Cost	Weight
Cast Iron, Fig. 521	$16.50	275 lbs.
Arc-Welded Steel, Fig. 522	8.43	127 lbs.

Bedplate in Which Elevation of One Unit is Greater Than Other Unit.—Bedplates in which the plane of support of the two units is the same have been previously discussed. A case where there is a difference in the elevation of the planes of support will be considered, an example being a large fan driven by a motor.

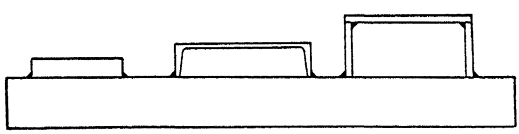


Fig. 523.

When the difference is small, the easiest way is to construct the usual type of bedplate and then place on top of it channels or angles.

There may even be cases where the use of a heavy plate is advisable, the additional cost of the metal being less than the cost of assembling a number of small parts. Illustrations of how various differences in elevations may be obtained are given in Figs. 523, 524, 525, 526 and 527.

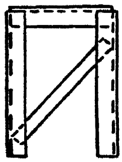


Fig. 524.

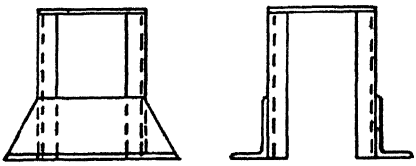


Fig. 525.

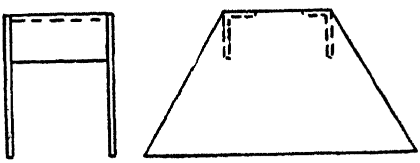


Fig. 526.

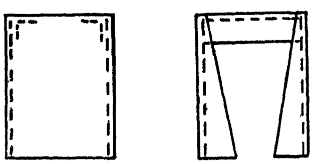


Fig. 527.

In some cases the weight on the higher elevation is so small that it may be taken care of by an extension beyond the dimensions of the bedplate (see Fig. 509). This is generally an unusual or special application, whereas the case in which the unit is supported at a higher

elevation and the support is directly on the bedplate is the more common one. The bedplate itself is laid out as has been previously outlined, so that consideration will only be given to the additional part involved.

A simple form, as shown in Fig. 524, consists of the very common structural type of construction. This is four angles with some cross bracing and some angles at the top to support the mechanism. This is very easy to assemble and is low in cost. It is assumed that this would be attached directly to the bedplate by welding and that the supports on the bedplate are directly underneath the apparatus which is on top of this pedestal and, therefore, the angles may come straight down.

Another design is shown in Fig. 525. This design calls for two channels with a plate on top and a mitred angle for use where the bedplate dimensions are wider than the top of the pedestal. Note that the angle is used where this pedestal is bolted to the main bedplate. Were the pedestal to be welded to the bedplate, the horizontal leg of the angle would not be necessary and in such case, a plate would be used instead.

A variation of the design, Fig. 525, is illustrated in Fig. 526. This construction is made up of two angles and two plates cut to the required dimensions. The angles are made relatively deep so as to obtain sufficient stiffness in that direction. If it is found necessary to get additional stiffness, other stiffener members may be placed in position.

All of these designs call for only standard structural shapes. Where better appearance is desired, it may be advisable to go to bent plates such as are shown in Fig. 527. This construction requires two plates cut and then bent and two angles welded to these plates. This gives a pleasing appearance and at the same time considerable stiffness in both directions.

The above illustrations show a general scheme of pedestal construction. Modifications of this general scheme will, of course, lead to a very great number of different designs but they may be essentially classified as indicated.

Bedplate Design by Diagram.—This discussion relating to the design of a line of bedplates, is intended to illustrate a design method rather than to provide working data for this specific application. It concerns a convenient method of using a plotted curve to arrive at design values. This plan can be applied to the design of many lines of machine parts with proper charts devised for each part.

This design method is for the determination of the size of the side members of a base, these side members may be angles, either of equal or unequal legs, channels or "I" beams. The ends are to be of suitable size angles to fit the side members.

It is assumed that there will be two units of equipment on the base and two general types of loading are involved.

First, the weights of the units are equal and each unit is placed the same distance from the end of the base, shown diagrammatically in Fig. 528.

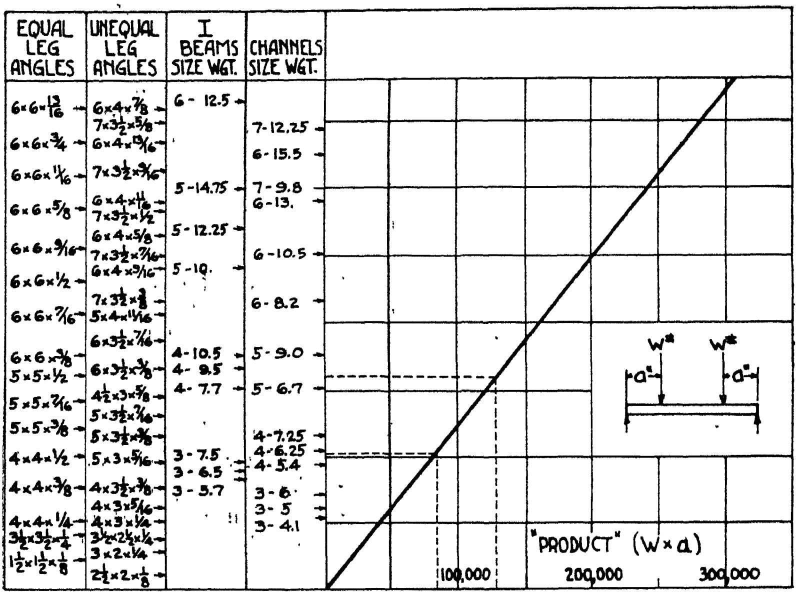


Fig. 528.

Second, the units are not of the same weight and are not the same distance from the ends. This is shown in Fig. 529.

W_1 W_2 a b LENGTH		W_1 and W_2=WTS. $W_1 < W_2$ K = 2			K = .4			K = .6			K = .8			K = 1.0 $K=\frac{W_1}{W_2}$		
LENGTH OF BASE→		4a	5a	6a	4a	5a	6a	4a	5a	6a	4a	5a	6a	4a	5a	6a
	C															
$C=\frac{a}{b}$	.3	.23	.37	.48	.28	.41	.51	.33	.45	.55	.38	.49	.58	.43	.53	.61
	.4	.43	.55	.61	.48	.60	.64	.53	.65	.68	.58	.70	.71	.63	.74	.74
$a<b$	.5	.55	.64	.70	.60	.68	.74	.65	.72	.77	.70	.76	.80	.75	.80	.84
L=4a	.6	.64	.71	.75	.69	.75	.79	.74	.79	.82	.79	.83	.85	.84	.87	.88
L=5a	.7	.69	.76	.79	.74	.80	.83	.79	.84	.86	.84	.88	.89	.89	.92	.93
L=6a	.8	.74	.79	.82	.79	.83	.84	.84	.87	.89	.89	.91	.92	.93	.95	.95
	.9	.77	.82	.85	.82	.86	.88	.87	.90	.92	.92	.94	.95	.96	.98	.98
	1.0	.80	.84	.87	.85	.88	.90	.90	.92	.93	.95	.96	.97	1.00	1.00	1.00

Fig. 529.

For both cases the length of the base may be expressed in terms of the distance (a) center line of one unit to the end of the base. That is, 4-a, 5-a, or 6-a or any other factor, these being the most common ones.

To find the size of the side members, simple methods may be followed. This will be considered under the two headings.

First, equal weight of units and equal distance from the ends.

"W" is the weight of a unit in pounds. "a" is the distance expressed in inches from the center line of a unit to the end of the base. Multiply "W" by "a" and this will give a certain "product". Referring to Fig. 528, a vertical line erected at that "product" will intersect the diagonal. At this point of intersection of a horizontal line extended to the left will indicate the sections which may be used for the side members of the base. Any section above this horizontal line will be acceptable, those sections nearest being the most economical.

As an example, assume that the weight of a unit is 4200 lbs. and the distance "a" is 20 inches from the end to center line of unit, 20 x 4200 equals 84,000. A vertical line at this point (84000) on Fig. 528 intersects the diagonal. From this intersection a horizontal to the left indicates a 4-inch 6¼ lb. channel or a 4½" x 3" x 7/16" unequal leg angle. A 4-inch 7-pound "I" beam or a 5" x 5" x ⅜" equal leg angle may be used, these being somewhat heavier than required.

Second type. Weights of units not equal and placed at different distances from the ends. W1 and W2 are weights of units in pounds, W1 being less than W2. "a" and "b" in inches are distances from the ends of the base. "a" for W1 and "b" for W2. (See Fig 529). "a" is less than "b". Divide W1 by W2 and call the quotient "K". Divide "a" by "b" and the quotient "c". Refer to Fig. 529 under "K", for the particular length of base expressed as a multiple of "a". Opposite "c" will be found a factor. Multiply W2 x b by this factor, and this will result in a certain "product". Then proceed as outlined above under the first type. A vertical line erected at this "product" will intersect the diagonal. At this point of intersection a horizontal line extended to the left will indicate the sections which may be used for the side members. As an example, assume a base 126" long with the smaller weight W1—3000 lbs., 21" from the end. The larger weight 5000 lbs., 30" from the end. Then K is 3000 divided by 5000 or .6.

$$C\,21/30\ (a/b) = .7$$

The base length is 126 or 6 x a. Under K .6 and the base length 6a, we find opposite C equals .7, the factor .86. 5000 x 30 x .86 equals 129,000. This is the "product". Referring to Fig. 528 at 129,000 we find as outlined above, under first type, that a 4-inch 8½ lb. I beam or 5" x 5" x ½" angle may be used. A 5-inch 9 lb. channel or 6" x 3½" x ⅜" angle will be just a little large.

Note the first case (equal weight of equipment and equal distance from end) is a special one of the second type. That is "K" equals 1 and "c" equals 1, and of course, the factor equals 1. Note also that "a" might equal "b" in which case "c" would equal 1 and the corresponding factors would be used as indicated under the different

values for K. If K and "c" and the base lengths are different than those given in Fig. 529 these factors may be easily obtained by estimating from the data given in Fig. 529. For example, supposing that the base is 5a but K is equal to .3 with a factor of C = .7. Under K = 2 and C = .7 the factor is .76 and correspondingly under K = .4 the factor is .80. .3 being halfway between .2 and .4, the factor "c" would be .78.

It is to be noted that while in general the sections given are the minimum weight sections for the required service there may be times when a heavier section will be desirable due to mechanical requirements other than the bare support of the equipment. It is taken for granted of course, that the side members will be completely welded into the end members.

Other Types of Bases.—The broad general classification of bases includes all types of bases. It may be easily visualized that by setting one of the bedplates shown up on end it may be commonly known as an end frame. By tying two of these together a complete framework for a machine may be formed.

Such end frames may be built in various manners, depending upon the design requirements. In some cases a single piece of heavy plate,

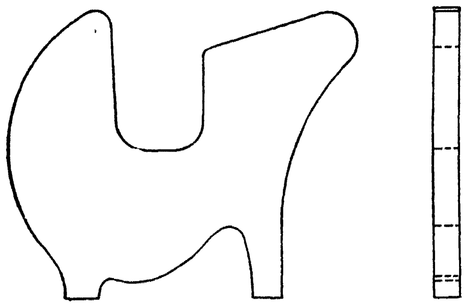


Fig. 530. A one-piece plate side frame for an inclined press.

flame cut to the required shape, Fig. 530, may be utilized. A pair of plates tied together by transverse plates to form a hollow built-up

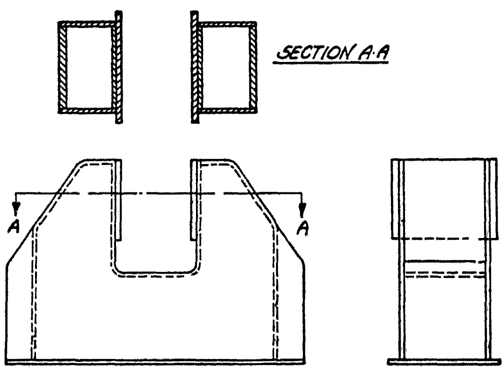


Fig. 531. End frame, for a bending roll, having a built-up section of steel plate.

section, Fig. 531, has many applications. Standard shapes may be used in vertical frames as in bedplates when tied together by bracing members of plate or shapes. Sometimes the main members of such frames may be built up as shown in the drawing, Fig. 532.

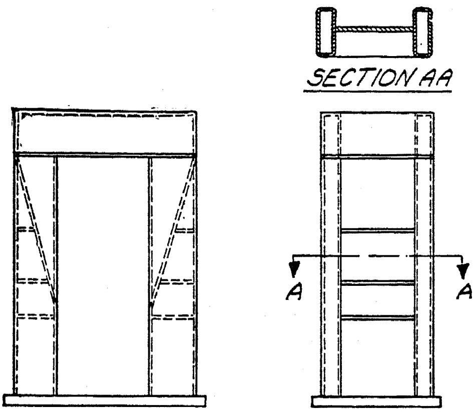


Fig. 532. Baling press end frame with main members composed of formed plate arc welded to form hollow section.

Regardless of how complicated the form of frame or bedplate it may be constructed of plate or standard or built-up sections. The more complicated the form the more advantage shown by arc-welded construction.

When construction of a machine of any type is contemplated, the most important consideration is service life and the cost of obtaining it. (See Page 383.) Comparing cast iron with steel shows that the latter has three times the strength of the former. (See Page 400.)

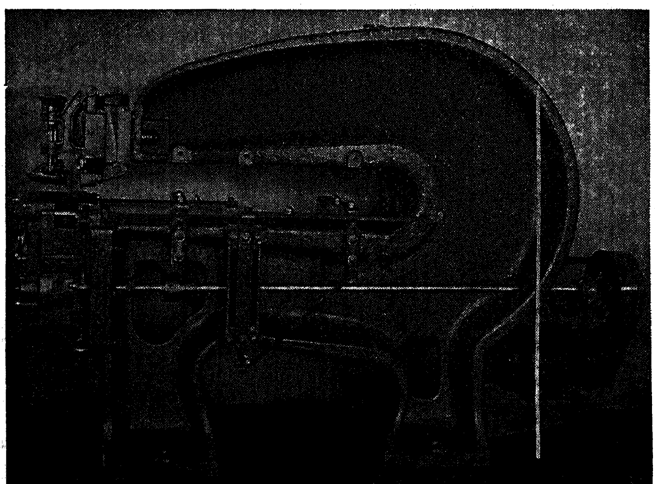


Fig. 533.

This fact must be kept constantly in mind; otherwise, a comparison between any two given machines might result in comparing a small-capacity cast machine with a large capacity welded machine on a first-cost basis only.

The machine to be redesigned is a shear used in shearing boiler plate up to ¼-inch in thickness at a speed of 10 feet per minute. The shear has a 50-inch throat and weighs 7500 pounds, built of cast iron. (See Fig. 533.) The cost is $450.00 not including the pattern. Principal dimensions are given in Fig. 534.

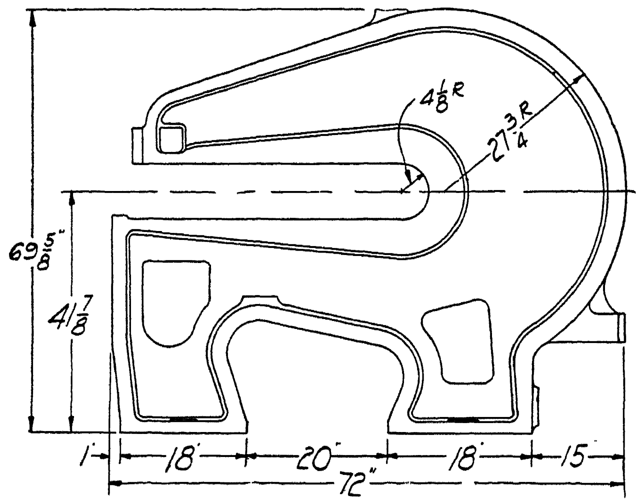


Fig. 534.

Preliminary calculations are based on the throat section of the shear since that is the critical section, see Fig. 535. No great error will be introduced if the sides of the flanges are considered parallel as in Fig. 536. The first calculations follow, using the values indicated:

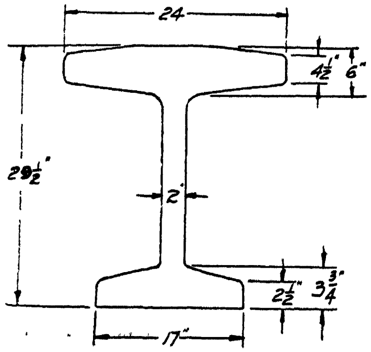


Fig. 535.

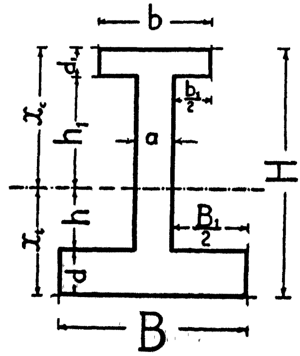


Fig. 536.

Applying the formula

$$X_t = \frac{1}{2}\,\frac{aH^2 + B_1d^2 + b_1d_1\,(2H - d_1)}{aH + B_1d + b_1d_1}$$

we have

$$X_t = \frac{1}{2}\,\frac{2\,(29\tfrac{1}{2})^2 + 22\,(5\tfrac{1}{4})^2 + 15 \times 3\,(2 \times 29\tfrac{1}{2} - 3)}{2 \times 29\tfrac{1}{2} + 22 \times 5\tfrac{1}{4} + 15 \times 3} = 11.75$$

then

$$X_e = 17.75 = (29.5 - 11.75)$$

The moment of inertia,

$$I = 1/3\,(Bx_t^3 - B_1h^3 + bx_e^3 - b_1h_1^3)$$

therefore

$$I = 1/3\,(24 \times \overline{11.75}^3 - 22 \times \overline{6.5}^3 + 17 \times \overline{17.75}^3 - 15 \times \overline{14.75}^3)$$

I = say 26,000 for the cast iron frame

However, the required moment of inertia of steel section is only 4/10 that of cast iron section or 10,400.

As a preliminary, assume a rectangular solid steel frame equal in depth to the throat section of the cast iron shear. Solving for b (Fig. 536):

$$I = \frac{bd^3}{12} = \frac{b \times \overline{29.5}^3}{12} = 10{,}400$$

then

$$b = \frac{12 \times 10{,}400}{\overline{29.5}^3} = 4.87, \text{ or, say, } 5 \text{ inches}$$

The total weight of material for this solid steel frame would be 64 x 64 x 5 x .29 or 5950 pounds. At three cents per pound, the cost of materials would be $178.50. The cost of machine cutting the 32 feet of 5-inch plate would be: Labor $2.50, overhead (at 200 per cent) $5.00, gas $5.76, $15.00 for set-up, or a total of $28.26. Allowing $12.00 for small additional parts and $15.00 for the feet, the total cost of materials and labor with the solid steel frame is $233.76.

Compared with the present cast iron frame (weight 7500 pounds, cost $450.00), the solid steel frame represents considerable savings.

The solid steel frame does not, however, represent a good use of metal since the shear so built has three times the strength of the cast iron shear. Equal strength can be provided by the most effective use of steel through an all-welded design, which will permit still greater savings in weight and cost.

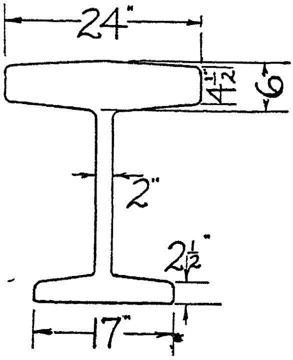


Fig. 537.

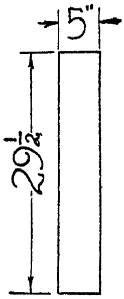


Fig. 538.

Note for example the cross section of the cast iron shear shown in Fig. 537. Such a cross section is necessary for cast iron but would be a waste of material if reproduced in steel. The next step would be a rectangular section as in Fig. 538. This, however, is also a poor use of material.

It is obvious that certain changes can and should be made in the design to make most effective use of the superior qualities of steel as compared with cast iron.

The solution is an all-welded design which will prevent waste of material and still provide the shear with equal service life to that obtained with cast iron. A still further reduction in weight and cost will be permitted.

In starting the all-welded design, the flanges are considered first without any reference to the web. Then the web is calculated and the flanges as first determined are modified so that the flanges plus the web give the required value for I.

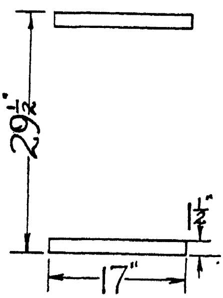


Fig. 539.

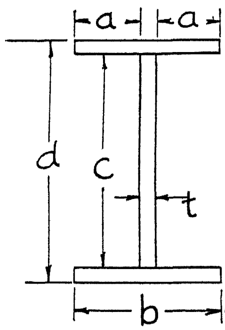


Fig. 540.

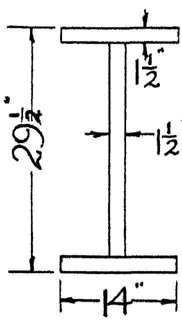


Fig. 541.

First, place two plates 29½ inches apart, inside to inside, as shown in Fig. 539. As the value for I for a 1-inch plate 1-inch long is 378 then for a 17-inch plate 1-inch thick, I would be 378 x 17 or 6420.

This is with no web and would indicate that a plate 1½ inches to 2 inches thick would be the proper size to use. (Note that a plate 24 inches wide would be nearly large enough, that is, I would equal 9100 in 1-inch size.)

A consideration of appearance, however, would indicate that the flange should not be too wide. For this reason, use is made of a flange 18 inches in width, the web being 1½ inches. On this basis, the calculation for I gives 10,400.

Calculating the values for this arc welded steel cross section, use is made of the accompanying Fig. 540 and the following formulae. Values of various parts of Fig. 540 are: $d = 29.5''$, $b = 18''$, $t = 1.5''$, $2a + t = b = 18''$, $2a = 18 - 1.5$, $a = 8.25''$.

$$I = \frac{bd^3 - 2ac^3}{12}$$

Substituting, we have $10{,}400 = \dfrac{18 \times \overline{29.5}^{3} - 2 \times 8.25c^3}{12}$

$$\begin{aligned}
\text{Solving for c: } 124{,}800 &= 462{,}000 - 16.5c^3 \\
16.5c^3 &= 462{,}000 - 124{,}800 = 337{,}200 \\
c^3 &= 337{,}200 \div 16.5 = 20{,}400 \\
c \text{ (Fig. 540)} &= 27.3''
\end{aligned}$$

$$\text{Solving for a: } 10{,}400 = (2a + 1.5)\ \overline{29.5}^{3} - 2a\frac{\overline{(29.5)}^{3}}{26.5^3}$$

$$\begin{aligned}
10{,}400 &= (2a + 1.5)\ 25{,}670 - 2a\ (18{,}600) \\
&= 51{,}340a + 38{,}505 - 37{,}200a \\
\text{Transposing } 14{,}140a &= 86{,}295 \\
a \text{ (Fig. 540)} &= 6.1, \text{ say } 6.25 \text{ inches}
\end{aligned}$$

This calculation gives the basic section for the all-welded design using standard steel plate. (See Fig. 541.)

Considering first the amount and cost of materials required in all-welded construction, it is found that the overall dimensions of the plate are 71 x 65. The weight, figured at 61.20 lbs. per sq. ft. for 1½-inch plate, would be 1970 lbs. The flanges, 14 feet wide by 1½-inches thick by 30 feet long, would weigh 2150 lbs. The total required is thus 4120 lbs. At 3c per lb., 4120 lbs. of steel would cost $123.60. The actual cost, however, will be less since approximately $4.50 will be recovered from scrap at 1c per lb. The material for all-welded construction is consequently $119.10. (Compare this with the $178.50 for materials with solid steel construction.)

The cost of cutting this 4120 lbs. of steel into proper shapes for arc welded construction would be as follows:

1 hour, at 60 ft. per hr.	$1.00
Overhead at 200%	2.00
Gas $\left\{\dfrac{30 \times 12 \times 1\frac{1}{2} \times .27}{100}\right\}$	1.46
	$4.46

In addition to the cost of cutting, $10.00 is added for set-up time, bending flanges, etc. Thus the actual cost of preparing the material for welding is $14.46.

Welding costs will include attaching the web to the flanges, welding on small brackets, etc. and for 25 feet of straight fillet welding.

Approximately 7.04 lbs. of electrode will be required per foot of weld in attaching the web to the flanges. This welding, done at the rate of 1.00 ft. per hour, would cost as follows:

Electrode (5 x 7.04 x .09)	= $ 3.15
Labor (5 ft. at 1 ft. per hr.)	= 10.00
50% operating factor	= 20.00
Cost, welding web to flanges	= $33.15*

*This estimate allows 5 feet of welding at the throat area where full strength is required.

The remaining 25 feet of welding can be straight fillet welds @ 8 feet per hour. The costs for this would be:

Electrode	$ 5.82
Labor	6.25
Overhead	12.50
Cost 25 feet of fillet welding	$24.57*

*This figure includes the cost of welding on small brackets, etc.

The above calculations for welding costs indicate that the total cost of welding is $57.72.

Recapitulating, the cost of building the shear of steel to an all welded design is:

Materials	$119.10
Cutting and labor	14.46
Welding (electrode and labor)	57.72
Total cost, arc welded shear	$191.28

A comparison of results with cast iron construction, steel (but not an all-welded design) and steel all-welded design is shown in the following table:

Item	Cast Iron	Steel (not all-welded)	Steel (all-welded design)
Weight, lbs.	7500	5950	4120
Cost, dollars	450.00	233.76	191.28

From this comparison, the advantages of the all-welded design are readily apparent. Tracing the redesign of the shear from cast iron to steel (not all-welded), then to steel (all-welded), the following particulars are to be noted:

In the transition from cast iron to steel, the weight of the shear was reduced from 7500 lbs. to 5950 lbs., a weight saving of 20%. Cost dropped from $450.00 to $233.76, a cost saving of 48%. Going from steel (not all-welded) to steel (all-welded), the weight of the shear was reduced from 5950 lbs. to 4120 lbs., or a further weight saving of 30%. Costs were also reduced from $233.76 to $191.28, a reduction of 19%, by use of steel and the all-welded design.

Comparing weight and cost of the shear built of cast iron and all-welded steel, it is evident that the all-welded design permits a weight saving of 45% and a cost reduction of 57%. These savings in weight and cost are made by arc welding without any sacrifice of strength, since the service life of the arc welded shear is at least equal to that of the cast iron shear, Fig. 533.

It is to be noted that the above figures on welding costs and the design for the steel shear are based on the physical characteristics of welds made by the shielded arc with the most modern equipment. Welding costs will be somewhat higher when other methods are used.

Conclusion — The Conventional Method of Design discussed in the previous pages is more accurate than the Direct Replacement Method and takes fuller advantage of the benefits of arc welded fabrication, assuring greater savings in cost and weight, and improvements in service economy. This method is the most common of the three approaches to welded design.

PRECISE METHOD OF DESIGN

By this method, unit stresses are figured carefully and the design is worked out in detail to meet service conditions very accurately. Where weight and performance are factors of utmost importance, then it is desirable to use this method to determine the unit stresses and required dimensions of material to obtain the most efficient utilization of material.

Roll Changing Hook — As an example of the Precise Method of Design in an assembly of simple elements, consider a roll changing hook. This is a hook to change rolls in a steel rolling mill. Dimensions and weight of the roll are given. Certain clearances for the hook are given. The hook is to be built so that the roll will be horizontal when carried in the hook. So that the point of suspension will not have to be altered to make the hook hang vertical when empty and loaded with different weight rolls, the hook is to be suspended on the center line of the rolls and counterbalanced.

In the following solution of this problem the values for stresses, etc. are for illustrative purposes and may be modified to suit specific applications.

The solution assumes that the extra weight of the commercial sections used is more than offset by the cost of calculating and fabricating sections of minimum weight.

Clearances are as shown in Fig. 542.

Calculated weight of roll — 39,000 lbs.

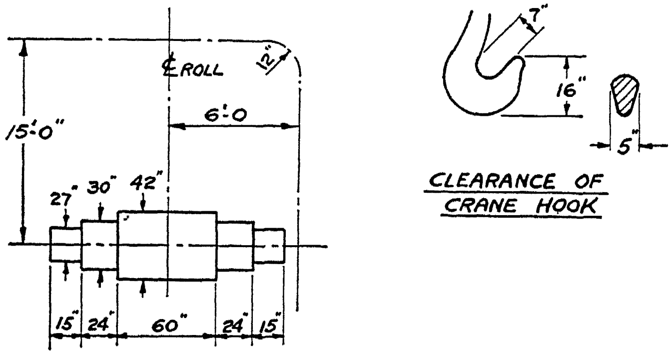


Fig. 542.

First Assumptions. — Straight sections of hook to be wide flanged I-beams. Curved section of hook to be I-beam section built up of three plates rather than attempt to bend the I-beam to the small radius necessary. Stresses allowed, 12,000 lbs. in steel and 7,000 lbs. in welds, to allow for abuse in service.

Rough calculation to determine approximate size of beam:

Moment/Stress times = Section Modulus

$$\frac{(72'' + 12'') \text{ x } [39000 \text{ lbs. (Roll)} + 7000 \text{ lbs. (Hook)}]}{12000} = 320$$

From United States Steel "Pocket Companion" CB-243 has section modulus 330 to 413, and is 24" high with 14" flanges, which are good proportions for the purpose.

The stress in the compression flange should be reduced on account of lateral deflection (see discussion of American Institute of Steel Construction Specification — Pocket Companion, Page 184) which is only recognized formula available but applies to floor or similar uniformly loaded simple beams. Beam under consideration is much more complicated than this being curved, reactions applied in different manner, which would induce greater lateral forces, but about two-thirds of the length is in tension, which will reduce lateral deflection.

The length of the compression flange is about 25 feet or about 22 times the width. The specification for simple beams reduces the tabular load (for length over width equals 22) to about 90%. For the conditions of this beam reduce the load on the compression flange to about 90% or 10,800 lbs. per sq. in.

The beam section roughly calculated above, CB-243 section modulus 330 has section area of 38.21 sq. ins. On an assumed total load or 46,000 lbs., roll and hook, the tension on the vertical portion of the hook throughout the I-beam superimposed on the cross bending is 46,000 lbs. / 38.21 sq. ins. = 1200 lbs. sq. in. By a coincidence this 1200 lbs. sq. in. is exactly the amount it was decided to reduce the load on the compression flange (which also reduces the load on the tension flange) and the beam roughly calculated is suitable for the vertical side of the hook. (If this superimposed tension had been greater or less the size of the beam would be increased to suit the allowed stress on the tension or compression flange respectively.)

In the top horizontal curved portion of the hook this tension effect is not apparent. The built up curved portion of the hook will reduce the moment arm and hence the bending stresses in the I-beam section by about two feet or more than a quarter. As this is much greater than the reduction decided for the compression flange, the I-beam section roughly calculated will do for this part too.

In a curved beam the stress on the inner flange is more than the stress in a straight beam of the same section at the same moment. (See Handbook of Engineering Fundamentals, Eshbach, Page 5-33 and 5-34.)

"12. Curved Beams"

"The derivation of the flexure formula, $s = Mc/I$, assumes that the beam is initially straight; therefore, any deviation from this condition introduces an error in the value of the stress. If the curvature is slight the error involved is not large, but in beams with a large amount of curvature, as hooks, chain links, frames of punch presses, etc., the error involved in the use of the ordinary flexure formula is considerable. The effect of the curvature is to increase the stress in the inside and to decrease it on the outside fibers of the beam and to shift the position of the neutral axis from the centroidal axis toward the concave or inner side.

"The correct value for the fiber unit stress may be found by introducing a correction factor in the flexure formula, viz., $s = KMc/I$; the factor K depends on the shape of the beam and on the ratio R/c, where R = distance, inches, from the centroidal axis of the section to the center of the curvature of the central axis of the unstressed beam; and c = distance, inches, of centroidal axis from the extreme fiber on the inner or concave side. Seely's Advanced Mechanics of Materials contains an analysis of curved beams and also Table VII which gives

values of K for a number of shapes and ratios of R/c. For slightly different shapes or proportions K may be found by interpolation with a fair degree of approximation."

Assume the design shown in Fig. 543 for curved portions.

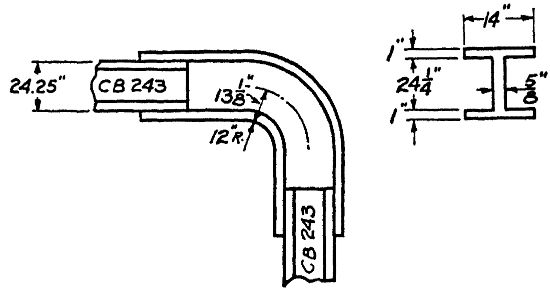


Fig. 543.

Section modulus = 400

Area section = 43.2 sq. in.

Bending stress on inner tension flange is increased (see Eshbach, Page 5-34 next to bottom figure right hand column, for

$$R/C = \frac{25\tfrac{1}{8}''}{12''} = 2.1) \text{ about } 1.33.$$

Tension in vertical portion of this member increases stress in tension side 46000 lbs. / 43.2 sq. in. = 1060 lbs. sq. in.

Beam should be calculated as straight beam in bending only for stress of $\frac{12000}{1.33} - 1060 = 7940$ lbs. sq. in.

Check assumed design: $\frac{46000 \text{ lbs.} \times 84''}{400} = 9660$ lbs. sq. in.

Beam section assumed should be increased: $\frac{9660}{7940} = 122\%$

Make curved portion of this section as shown in Fig. 544.

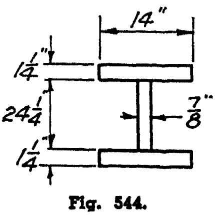


Fig. 544.

Calculations of principal welds:—

Make welds to develop full strength of members used. Use ⅞" fillet weld to connect flanges of curved and straight portions.

Strength of ⅞" fillet weld is derived as shown in Fig. 545.

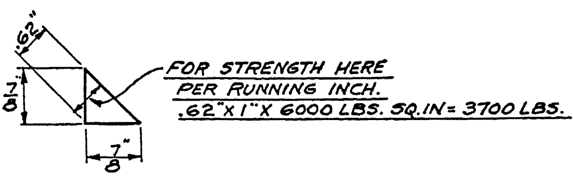


Fig. 545.

$$\frac{14'' \times 1\frac{1}{4} \times 12000}{3700} = 57 \text{ inches weld.}$$

Weld web to flanges clear through with "V" welds or two ½" fillet welds. This is more than actual requirements for shear.

Make welds as shown in Fig. 546, so that there will be no abrupt change in section of flanges and no heavy welds directly across an important tension member.

The socket to engage the end of the roll, as shown in Fig. 547, would be cheaper as a steel casting than a built up welded construction. Check to see if sufficient welding can be developed on this design.

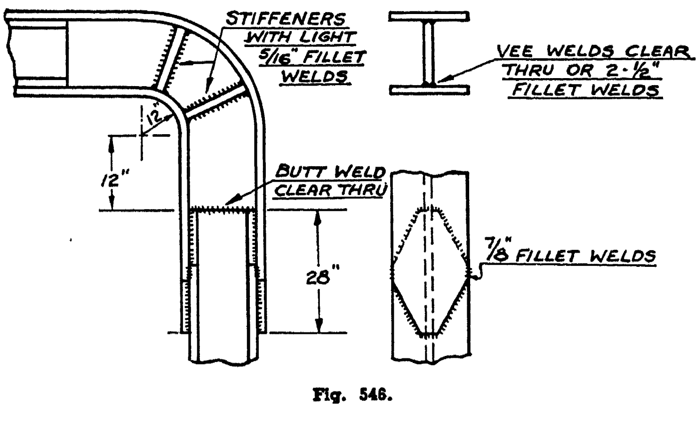


Fig. 546.

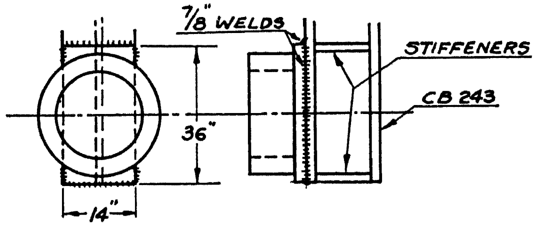


Fig. 547

Assume, to be safe, weld fails by tension on top and compression on bottom, turning through center rather than turning on bottom.

Section modulus of weld (refer to Fig. 548)—

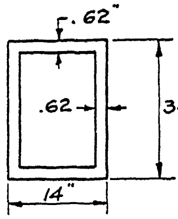


Fig. 548.

Section modulus = 550

$$\text{Section modulus required} = \frac{46000 \times 84}{6000 \text{ lbs./Sq. In.}} = 644$$

Section modulus above section deficient by 644 — 550 = 94.

Add additional welding at top and bottom of above rectangle:

$$\frac{94}{.62'' \times 36 \text{ (about)}} = 5$$

Add wings to casting to engage stiffeners between the flanges of the beams, as shown in Fig. 549.

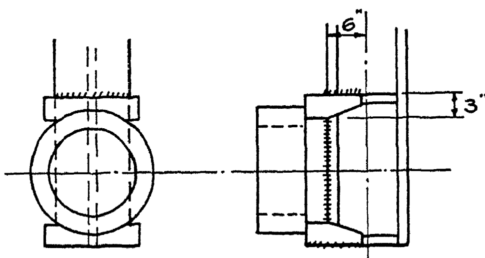


Fig. 549.

A 6″ horizontal dimension of wings adds 6″ welding at top and 3″ vertical dimension eliminates 3″ weld, giving 6″ net weld on two welds at top and 6″ net on bottom.

Top Clevis (see Fig. 550) —

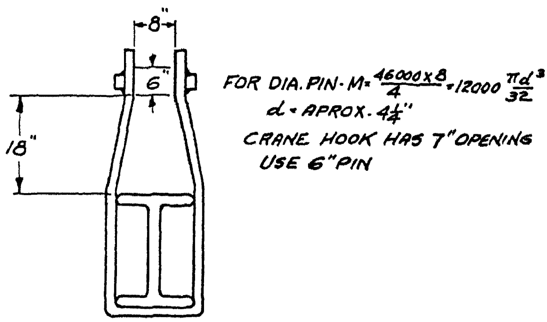


Fig. 550.

Bearing on Pins: $\frac{46000}{4 \times 12000} = 1''$ thickness for two plates, or $\frac{1}{2}''$ plates. Use at least $\frac{3}{4}''$ plates, or better, $1''$ plates to provide side stiffness.

The hook now appears as shown in Fig. 551.

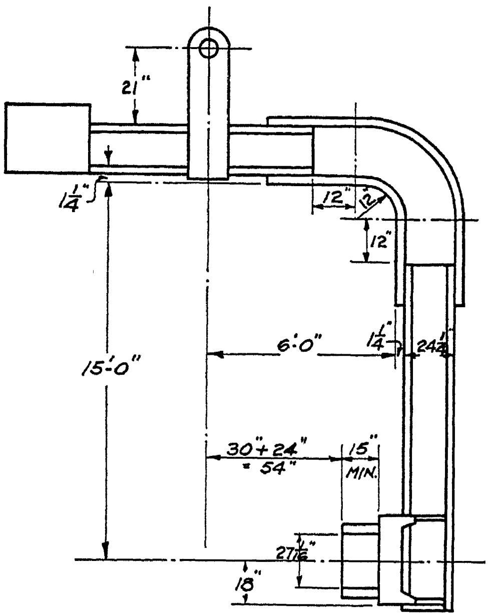


Fig. 551.

Approximate calculation of deflection is as follows (refer to Fig. 552):

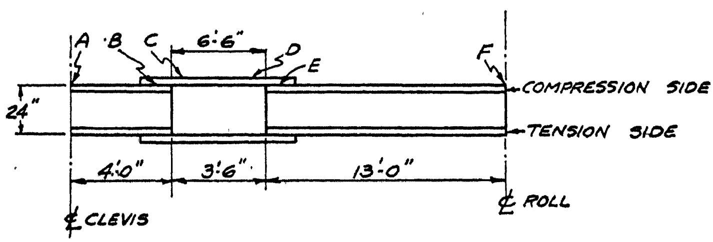


Fig. 552.

Stresses at		*Tension*	*Compression*
A		0	0
B	$\dfrac{48 \times 46000}{330}$	6.700	6.700
C	$\dfrac{48 \times 46000}{500} \times \dfrac{.85^*}{1.33^*}$	5.900	3.700
D	$\dfrac{85 \times 46000}{500} \times \dfrac{.85^*}{1.33^*}$	10.500	6.700
E & F	$\dfrac{85 \times 46000}{330}$	11.800	11.800

*Factors from Eshbach, Page 5-34

		Tension	Compression
Deflection AB	$\dfrac{6700/2}{33000000}\,48$	.0049	.0049
CD	$\dfrac{5900 + 10500}{33000000 \times 2}\,42 \quad \dfrac{3700 + 6700}{33000000 \times 2}\,78$	.0105	.0124
EF	$\dfrac{11800}{33000000}\,156$	.0558	.0558
		.0712	.0731

Angle of deflection is about:

$$\frac{.0712 + .0731}{24 \text{ depth of section}} = .072''/12''$$

Deflection-roll in socket is $\frac{1}{16}''$ in $15''$ length, or .04 in $12''$.

To hold roll horizontal socket should be tilted above horizontal: .07 + .04, or about $\frac{1}{8}''$ per foot.

The calculation of the counterweight is simple, and need not be worked out in detail here.

Conclusion — In this discussion of the Precise Method of Design, it has been pointed out that by accurate calculation of stresses, the minimum amount of material is required to meet the service requirements.

SHAPES AVAILABLE FOR WELDED DESIGN

Standard Rolled Shapes — The assembly of sections and shapes into a completed part leads to a further consideration of these elementary parts. Available standard rolled shapes of a wide variety are shown in Fig. 553.

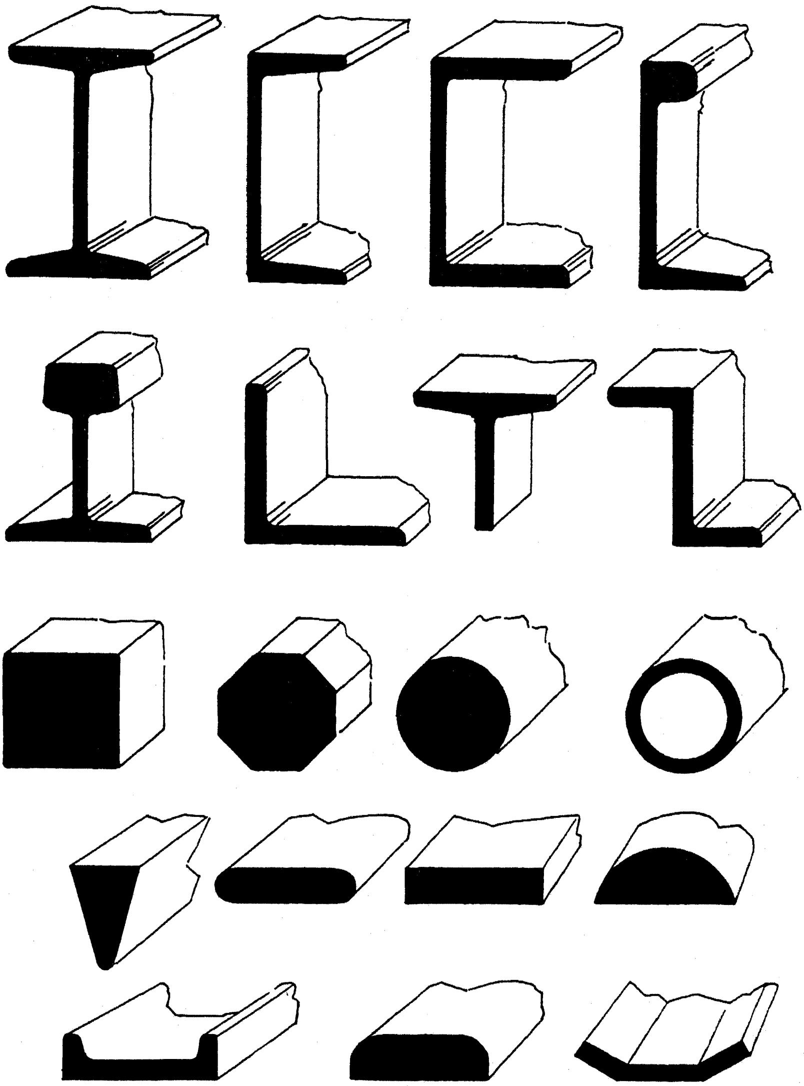


Fig. 553. Standard rolled shapes.

Joining Standard Rolled Shapes — When the particular section or sections have been determined to meet design requirements, consideration is then given to the method of joining them. An explanation of various procedures is given in the different combinations of standard rolled shapes shown in Figs. 554 to 565.

Each of these joints should be considered from the same general viewpoints — (1) Cost of preparing the parts. (2) Welding cost. (3) Handling cost (4) Appearance.

Preparation involves cutting. A straight cut costs less than other types. It will be assumed that the same cutting equipment is used throughout, the variables being the length of the cut and its shape. Welding cost is affected by the length of the weld and the ease of welding. Flat welding is most economical. (See Page 211.)

Set-up of the work requires that the joints be so arranged that the welds may be easily made, preferably in one position — flat.

To obtain a pleasing appearance, often it is only necessary to make slight changes in dimensions at a slight or negligible increase in cost. However, where appearance is a vital factor (see Page 380) it must be most carefully considered. Keeping these items in mind, inspection of the following joints affords a ready comparison.

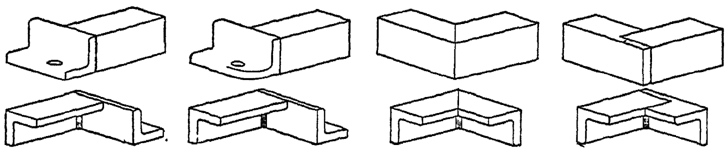


Fig. 554. Angle to angle—same size.

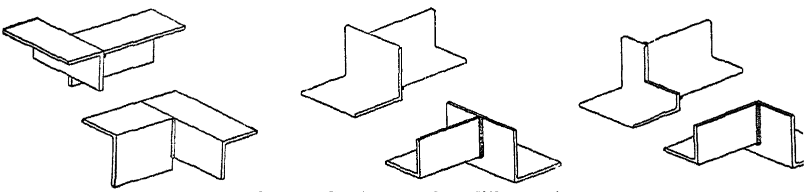


Fig. 555. Angle to angle—different size.

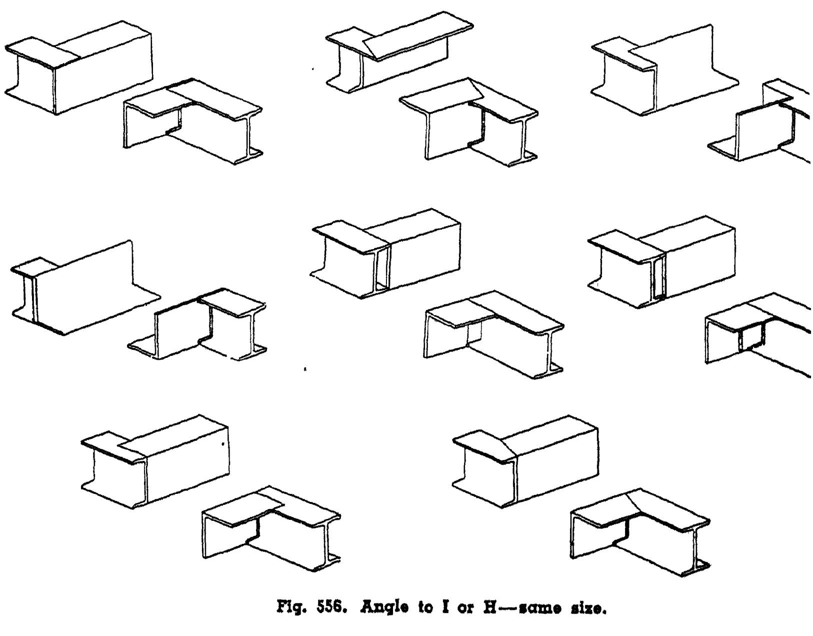


Fig. 556. Angle to I or H—same size.

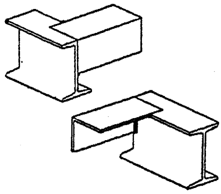


Fig. 557. Angle to I or H—different size.

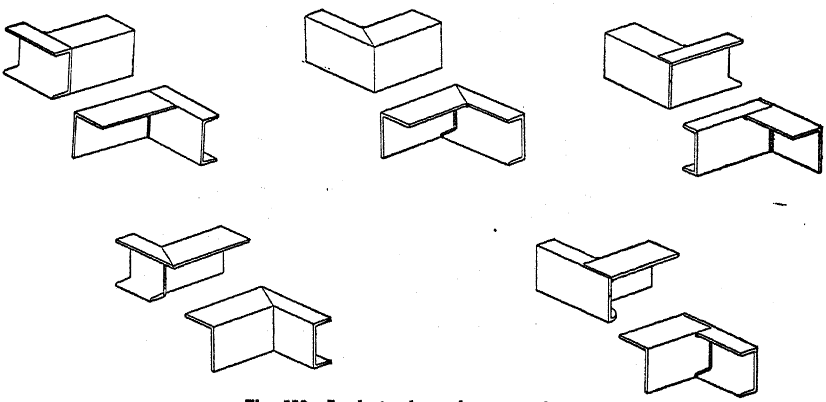


Fig. 558. Angle to channel—same size.

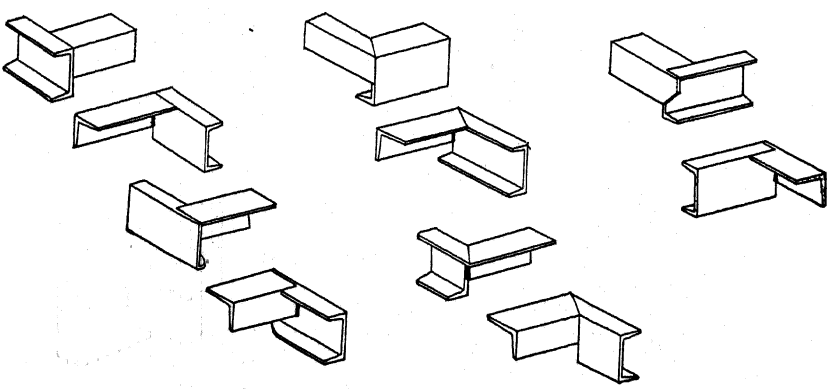


Fig. 559. Angle to channel—different size.

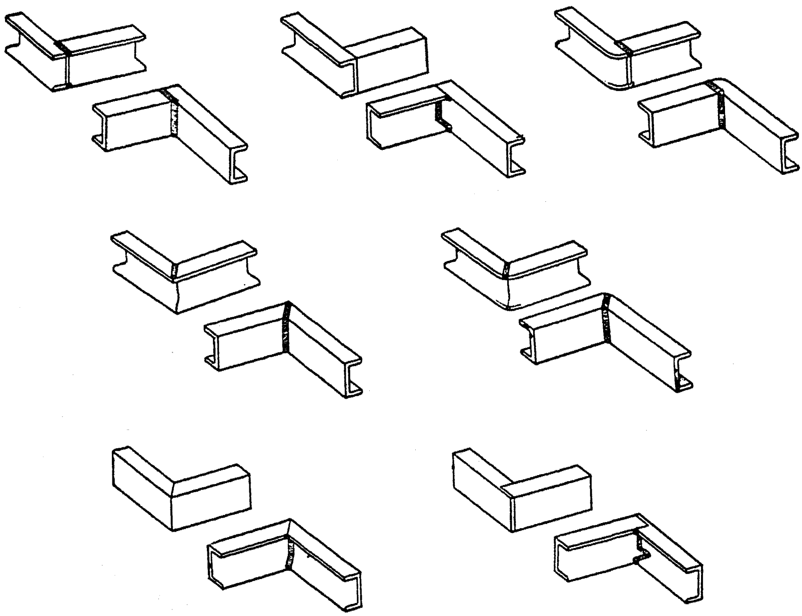


Fig. 560. Channel to channel—same size.

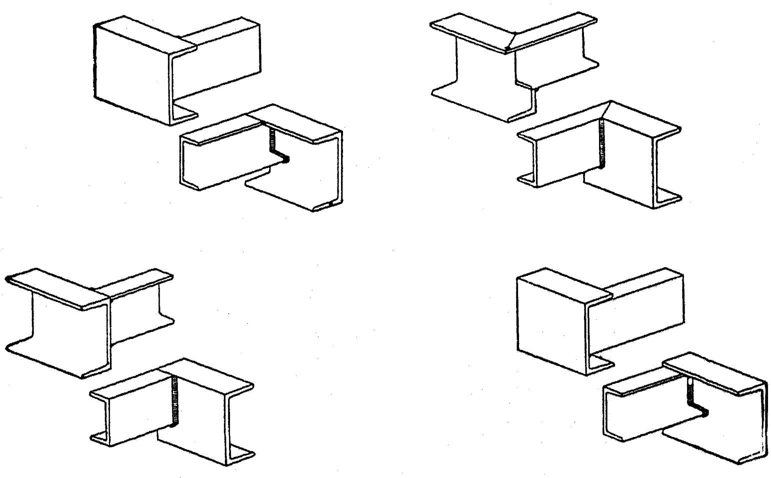


Fig. 561. Channel to channel—different size.

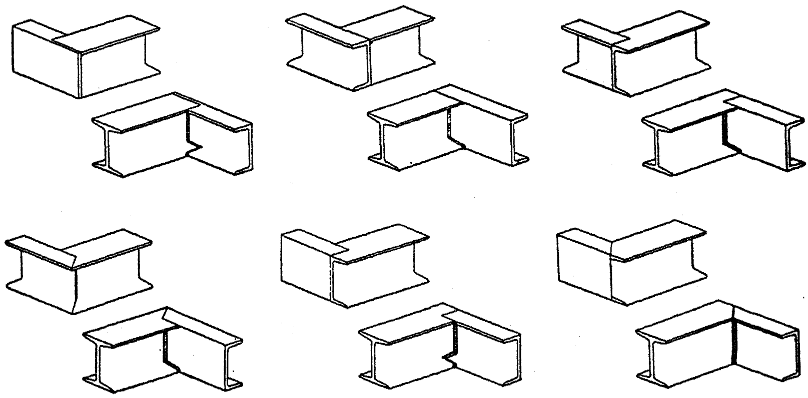


Fig. 562. Channel to I or H—same size.

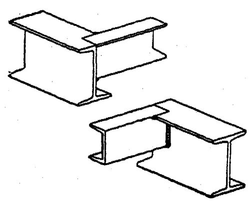


Fig. 563. Channel to I or H—different size.

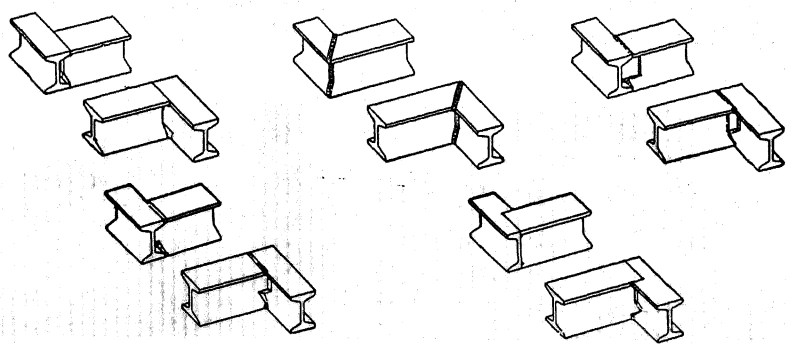


Fig. 564. I or H to I or H—same size.

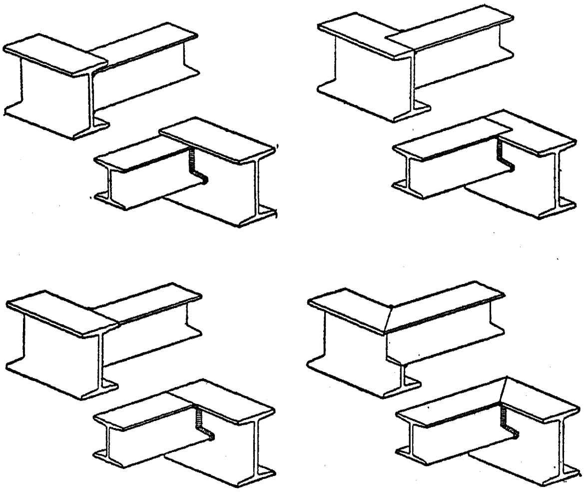


Fig. 565. I or H to I or H—different size.

Tubular Shapes—A similar study may be made of tubes. A tubular section is known to be the most efficient for application where a large amount of torsion is involved. It is for this reason that airplane fuselages are constructed chiefly of tubular shapes. Certain types of bedplates may be subjected to extreme torsion and in such cases it may be advisable to use tubular bracing or even main members of tubular shape to resist the torsion imposed. Typical applications are illustrated in Figs. 566 to 570. Welding has made available the use of tubular sections for this purpose, because it permits connections being made directly to other members without the use of a mechanical connecting member. Welded connections can be made of tubular shapes, or tubular shapes and structural shapes at any angle.

This freedom of design, with tubular steel members is just one of the many ways in which welding makes possible economies that cannot be obtained by any other method of fabrication or construction.

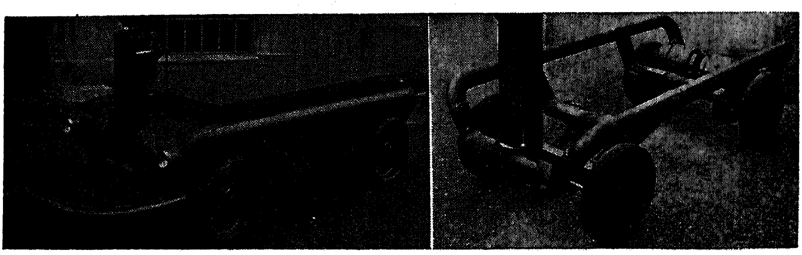


Fig. 566. Small electric truck with welded tubular frame.

The simplest connection is a straight end-to-end butt connection of the same size tubular shapes. This may be a plain butt joint (Fig. 571) or a butt joint with back-up ring (Fig. 572). The backing is of great assistance in assembly and may permit higher welding speeds. The butting ends may be straight or scarfed, depending upon the thickness of the tube wall.

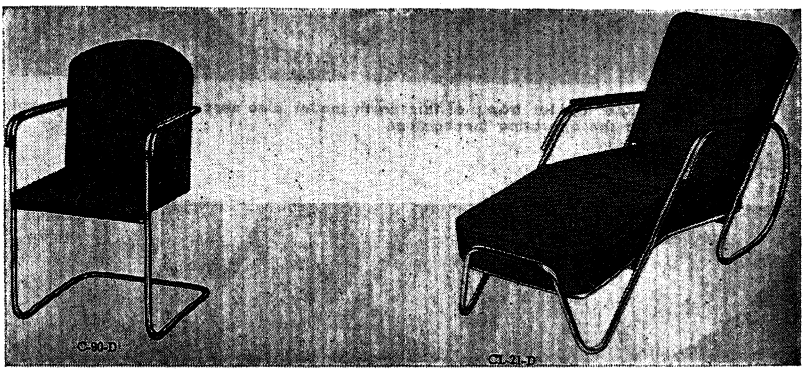


Fig. 567. Tubular furniture of arc welded construction.

When one tube must be connected to another at an angle, the connection can be designed in several ways. The end of one tube may be cut to fit a curved surface on the second member, as shown in Fig. 573, or a hole may be cut in the wall of one member to permit insertion of the other member, see Fig. 574. This hole should be of such shape as to permit a close fit with the inserted member at the desired angle. Both types of joints require a fillet weld.

Fig. 568. Structure, stairway and railing of welded tubular construction.

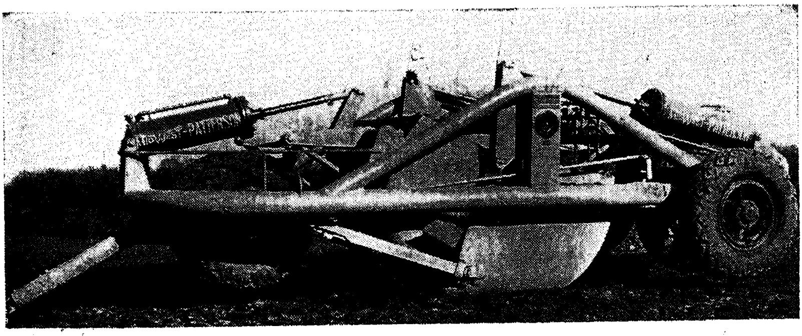


Fig. 569. The rigid tubular frame of this earth mover also serves as an air reservoir or pressure tank for the operating mechanism.

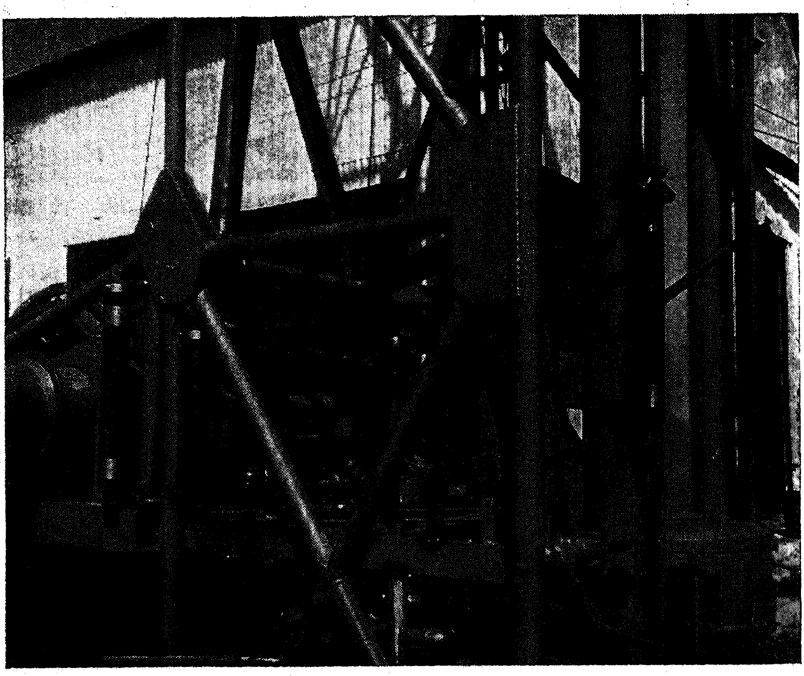


Fig. 570. Portable oil derrick of welded tubular construction.

One advantage offered by the type of connection shown in Fig. 574 is that in assembly of several members simpler jigs or fixtures may be required to hold the assembly in alignment for welding.

When it is desired to join the ends of two tubular members other than at a straight angle, any one of several types of joints may be used. The joint, Fig. 575, is the simplest of this type, the ends of both

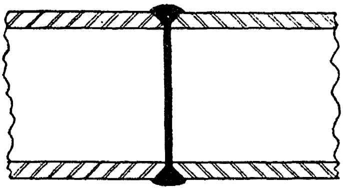


Fig. 571.

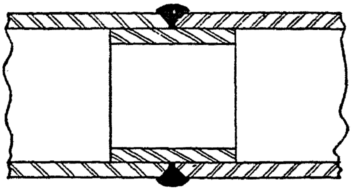


Fig. 572.

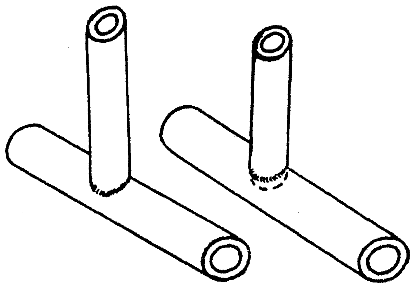


Fig. 573. Fig. 574.

members being mitred to the desired angle to form a butt joint for welding. The sharp corner shown in Fig. 575 may be eliminated by the use of one or more additional members.

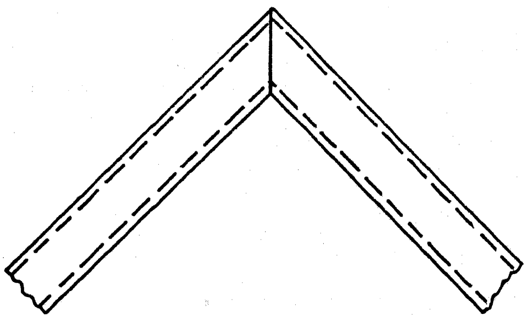


Fig. 575.

Fig. 576 shows the use of one additional member which requires two welded joints.

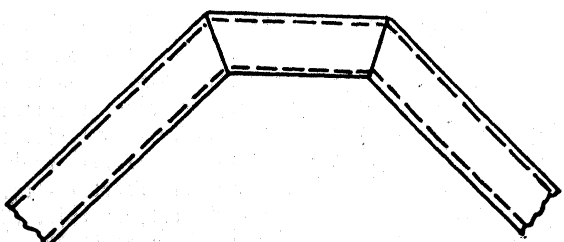


Fig. 576.

Improved appearance may be obtained by use of a special fitting which requires two plain butt welded joints, as shown in Fig. 577.

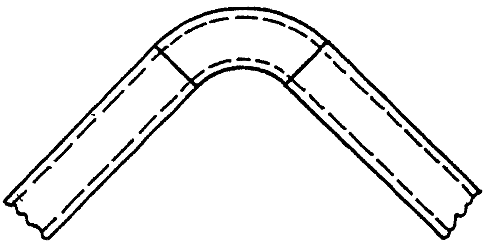


Fig. 577.

These designs and connections of tubular members in the same plane are basic; many variations of these designs are possible. In designing connections consideration should be given not only to appearance, but also to the amount of cutting and welding required.

Comparison of Tubular Shapes to H Beams.—The comparison will be made first on the basis of the same area or weight per foot, taking as example, 4″ x 4″, 5″ x 5″, 6″ x 6″ and 8″ x 8″ H-beams such as shown in Table I.

TABLE I—H-BEAMS

Size	Weight Lbs./Ft.	Area Sq. In.	Moment of Inertia	
			Max.	Min.
4″x4″	13.8	3.99	10.7	3.6
5″x5″	18.9	5.47	23.8	7.8
6″x6″	22.5	6.66	41	12.2
8″x8″	34.3	10	115.5	35.1

The moment of inertia which is a measure of the deflection, is for the smaller value, only about a third of that of the larger value.

For this same area or weight per foot the moments of inertia for a 4″, 5″, 6″ and 8″ diameter pipes which would take the same over-all dimensions as the above-mentioned H-beams (although not occupying the space as economically as the H-beam does), are calculated and shown in Table II. They are approximately twice the minimum moments of inertia of the H-beams and approximately 70% of the maximum moments of inertia of the H-beams. It is also to be carefully noted that this moment of inertia exists in all directions and therefore the pipe may be loaded in any direction desired, provided the required moment of inertia does not exceed the values given in Table II.

TABLE II — PIPE OF SAME OVERALL DIMENSIONS AND WEIGHT PER FOOT AS H-BEAMS, TABLE I

Diameter	Wall Thickness	Moment of Inertia
4″	0.36″	6.8
5″	0.38″	15.0
6″	0.38″	27.0
8″	0.41″	72.5

If the thickness of the pipes is increased so as to obtain the same moment of inertia for the pipe as the maximum moment of inertia of the H-beam, there is a considerable increase in weight for a given deflection. Up to this point merely the straight loading or the beam loading of this particular type of structure has been considered.

TABLE III — PIPE HAVING MOMENTS OF INERTIA EQUAL TO MAXIMUM VALUES FOR H-BEAMS, TABLE I

Diameter	Wall Thickness	Moment of Inertia
4″	0.73″	10.7
5″	0.76″	23.8
6″	0.67″	41.0
8″	0.75″	115.5

Obviously, the use of a pipe would not be economical where it was just a plain case of bending in a single plane, but where it is a case of torsion, that is twisting, or a case of combined twisting and bending, then the pipe is exceedingly economical. It would take a rather involved mathematical demonstration to show the characteristics of the tube in torsion, but it is obvious that the metal is displaced all around the center point, which is the center line or axis of the tube and therefore is distributed to the best possible advantage, whereas in the case of the H-beam it is not so distributed and for pure torsion would therefore not act so effectively.

A pipe is the best structural member for the use of combined bending and torsion or just pure torsion, and it is obvious as shown in the case of the minimum moment of inertia of the H-beam, that a pipe for the same weight is superior to the H-beam for this minimum moment of inertia, which might be, and in some cases would be, the direction of the load and therefore the H-beam would not be particularly satisfactory.

It is of course obvious that the H-beam represents the most economical distribution of metal for a direct loading or bending moment, whereas the pipe represents the most economical distribution of metal

for torsion. It should be noted, however, that the pipe is more economical for torsion and bending than is the H-beam, and the more the torsion predominates the more the superiority will be evidenced.

The method of determining what should be used should be the same as that followed in the case of the beam, that is, the number of inch pounds and the cost of these inch pounds, keeping in mind of course that the deflection must be the same in all cases.

In the case of columns, deflection for a given load is dependent upon the ratio of $\frac{l}{r}$, called the slenderness ratio. l is the unsupported length of the compression or column member and r the radius of gyration. In the case of a tubular shape, due to its symmetry r has a single value, whereas in the case of H or I-shapes this is not true. Therefore when considering the latter shapes the least value of $\frac{l}{r}$ must be used to obtain the design which will meet the requirements, i.e.: the minimum strength value must be used.

Special Fabricated Shapes.—Unusual or special shapes may be produced by (1) joining standard rolled shapes (see Fig. 578) and (2) joining special formed shapes such as stampings, forging, castings, etc.

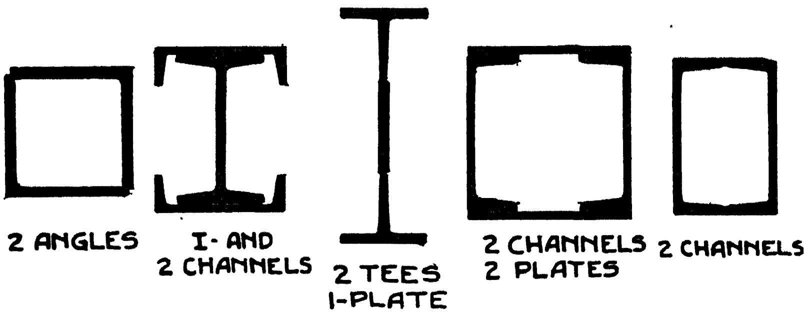


Fig. 578.

DESIGN EXAMPLES

Assembly Details.—The sections and shapes discussed previously are used to produce assembly details such as the following:

Bosses.—Stud bosses may be applied in various ways, depending upon their functions. In Fig. 579 the boss consists merely of a piece of round bar stock or shafting fused to the supporting member by a fillet weld as shown. This boss may perform as supports for other parts. If tapped as indicated it may serve as a stay rod connection or may support a slotted bar used for adjustment purposes.

The boss shown in Fig. 580 may be either drilled or tapped. It may serve the same purpose as the boss shown in Fig. 579. However, this design permits use of a longer stud. The boss is inserted through a hole in the supporting member. Fillet welds around the circumference of the boss hold it securely in place.

When it is advisable to drill a hole in the supporting member and where a finished boss is desired on one side of the member, the type shown in Fig. 581 may be used. The hole in the supporting member locates the boss and the boss is permanently secured by a fillet weld. The shoulder on the boss acts as a stop on the opposite side from the weld. This type of design is often used in gear case construction where a machine boss on the inside is required and the space available is limited.

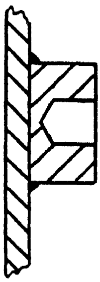


Fig. 579.

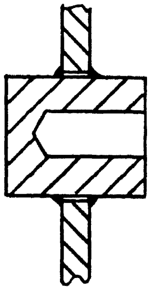


Fig. 580.

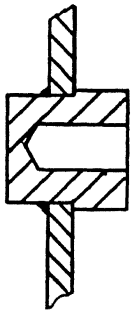


Fig. 581.

Fig. 582.

Bosses in thin plate and sheet metal are often designed as shown in Fig. 582. A hole of slightly smaller diameter than the outer diameter of the boss is punched in the supporting member and the boss forced through the punched hole. A fillet weld is applied.

These bosses may be drilled all the way through, and in such cases serve as shafting or lever rod supports.

Bosses may also serve as pads to provide proper mounting of equipment. See Fig. 579. However, mounting pads may be made in any size or shape.

Where pads of considerable area are required and low height, steel plate cut to the required dimensions and fillet welded to the supporting member will serve. The pad may be machined before welding to the supporting member. Where such type pads are required but of greater

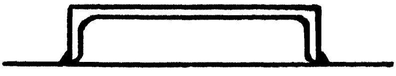


Fig. 583.

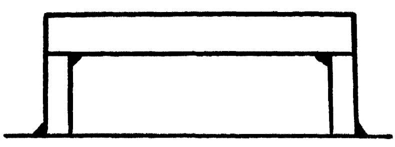


Fig. 584.

height, they may be built up of structural shapes or plate, Figs. 583, 584 and 585, or in cases of mounting light equipment plate may be formed to the required dimension and shape on a bending brake. See Fig. 586.

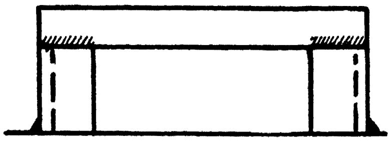


Fig. 585.

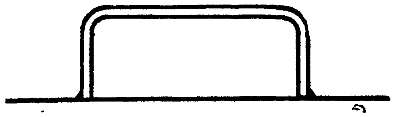


Fig. 586.

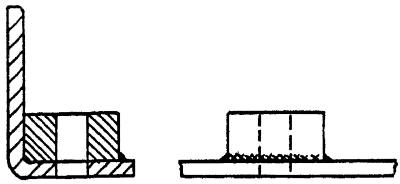


Fig. 587.

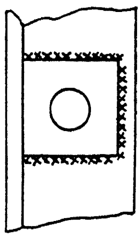


Fig. 588.

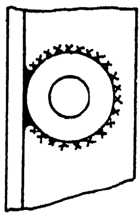


Fig. 589.

Common use of bosses is for foundation or holding down bolts, the reason being accessibility and clearance for wrenches. The cross section, as indicated in Fig. 587, is the same for the bosses Figs. 588, 589, 590 and 591. The difference in the construction is clearly indicated in the plan view. The only real difference is perhaps the appearance. Figs. 588 and 589 are low in cost being cut from standard stock and are then ready for welding, whereas Figs. 590 and 591 are cut from stock and are further machined.

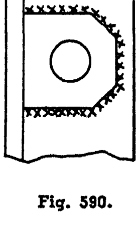


Fig. 590.

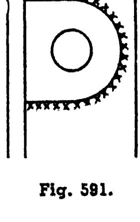


Fig. 591.

Bosses similar to those shown may also be applied to the vertical sides of bases, as shown in Fig. 592.

Rounding corners and machining to special shapes involve an additional expense. Quite frequently, this additional expense may be somewhat reduced by constructing the boss of a number of parts. A typical one, Fig. 593, is made of a top plate cut to the desired shape and this is supported by a vertical plate bent to conform to this shape of any form such as round, hexagonal, etc. The cover plate is welded on the inside of the vertical plate and then the boss is welded in place. It may be advisable to place a spacer such as a pipe section between the cover plate and the main part of the base to make it easier to insert the holding down bolts. In other cases it may be advantageous to make the hole in the base considerably larger than the hole in the cover plate so that the foundation bolts may be readily moved about and any variation in their location taken care of by the base. A further and perhaps similar modification of this would consist of an angle welded as shown in Fig. 595. This type of boss

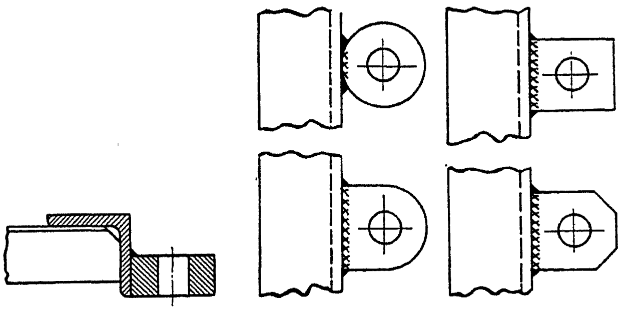


Fig. 592.

permits the use of a continuous oil drain a flat strip formed on a bending brake to the indicated shape and welded in place, entirely around the base.

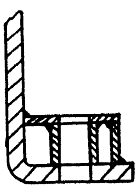


Fig. 593.

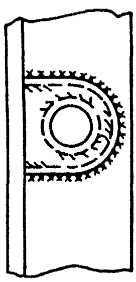


Fig. 594.

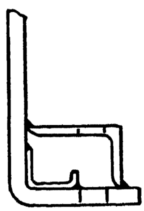


Fig. 595.

Bearings.—Bearings may be considered as a modification of bosses but are of much more importance in the successful operation of a machine because the bearing is the point at which the load is taken. In general it must be so designed as to take the load and transmit it to supporting members of the machine.

The simplest bearing is pipe placed on a flat supporting member and welded thereto, Fig. 596. Where the bearing must be raised considerably above the support a pipe supported by a block (Fig. 597) may be used. This block may be shaped to give a good appearance

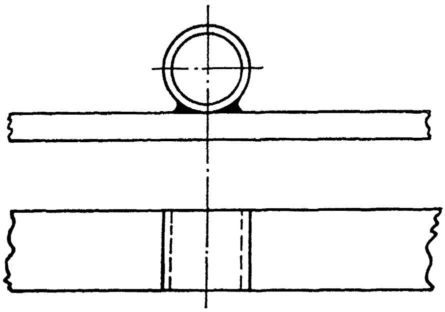


Fig. 596.

or it may be merely a rectangular shape. This involves more welding than Fig. 596 but it does not require raising the support as a whole.

Another type of bearing consisting of two plates welded to the support (Fig. 598) is used frequently in cases where levers are involved. Simple and easily constructed, the bearing may be made of plates cut to the desired shape.

A modification of the bearing shown in Figs. 596 and 597 is shown in Fig. 599. This consists essentially of a split tube with plate stiffeners on the side and bosses at the split for obtaining a slight variation in the diameter of the bearing.

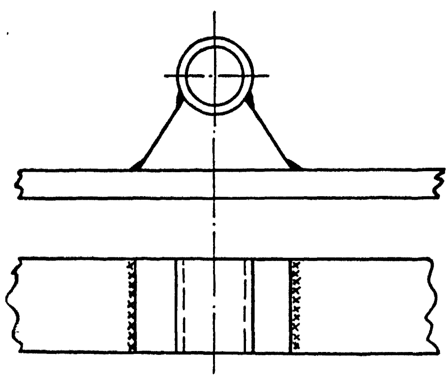


Fig. 597.

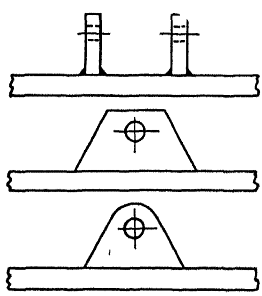


Fig. 598.

Split bearings, where the bearing cap must be removable (Fig. 600) consists of a plate bolted to the machine. To this is welded the lower half of the bearing. The top or cap is bolted to the lower half. The blocks, shown rectangular, may be modified as to shape to meet the requirements of the design.

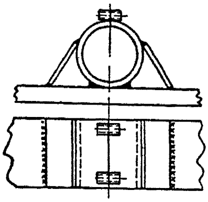


Fig. 599.

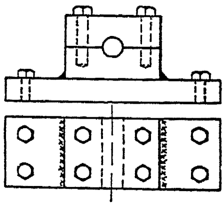


Fig. 600.

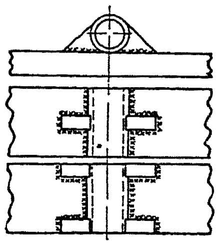


Fig. 601.

Where a relatively small bearing, or an inexpensive type is needed which must be braced in a line parallel to the support, two types of bracing are shown in Fig. 601 a single brace in the center of the bearing used for relatively short bearings or braced at the ends for longer bearing.

It should be kept in mind that the loads which the bearing has to support and transmit can be taken care of by welding the bearing to the supporting member at extremely low cost and that the location of the bearing is not governed by any conditions other than the requirements of the design. Stiffeners and connection plates may be so located and so welded to the other parts of the machine as to give excellent design with low cost.

Fig. 602 shows bosses in a gear case. The lines of force are taken care of by placing these stiffeners or braces or ribs directly in the line of the lines of force so that the stress which is coming on any one of these is amply taken care of.

In the detail of a machine base (Fig. 603), the load is carried by means of stiffeners from the point of application through to the ultimate support.

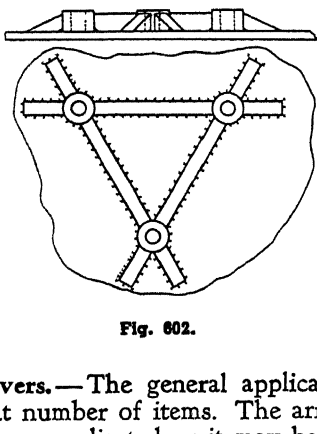


Fig. 602.

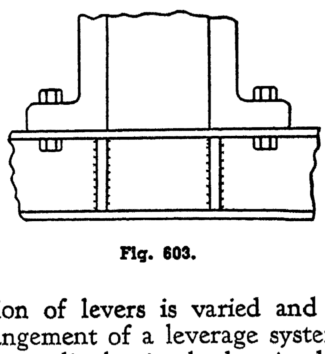


Fig. 603.

Levers.—The general application of levers is varied and covers a great number of items. The arrangement of a leverage system may be very complicated or it may be exceedingly simple, but in the final analysis it all comes down to a question of a combination of simple levers.

The lever shown in Fig. 604 is a very common type, generally keyed to a shaft so it may be used in either or both directions. A piece of flat stock, shaped for appearance and with boss or bosses with a keyway to fit the shaft is required. Bosses may not be necessary, the amount and type of the load determining their use.

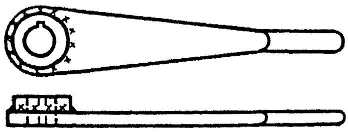


Fig. 604.

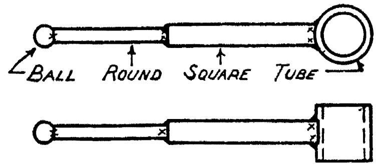


Fig. 605.

Another lever (Fig. 605) of the same general type designed to meet certain limiting mechanical dimensions is more expensive, as it is made up of a number of parts welded together. The appearance of the simple lever has been greatly improved.

In some cases a lever (Fig. 606) to resist unusual forces, consists essentially of a tube or pipe, around which is fitted some flat stock which has been punched at one end and bent (these operations

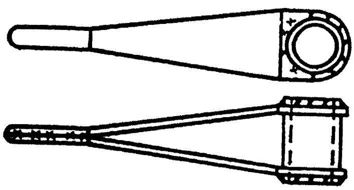


Fig. 606.

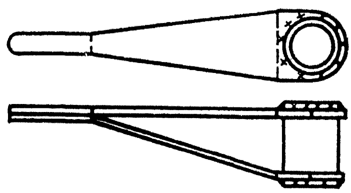


Fig. 607.

occurring after it has been cut to shape). The lever symmetrical about the center line has considerable stiffness in both directions. This lever, easily may be modified for operation (Fig. 607) where the point of application is not in the center line with the two points of support.

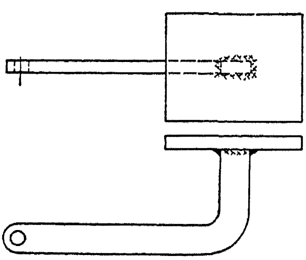


Fig. 608.

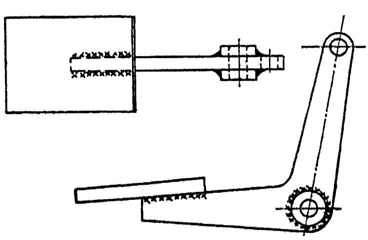


Fig. 609.

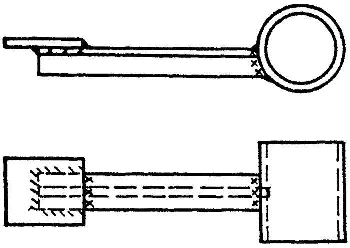


Fig. 610.

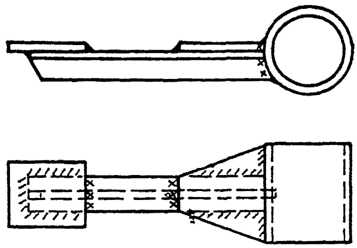


Fig. 611.

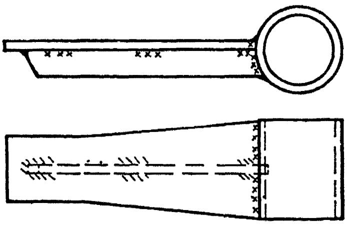


Fig. 612.

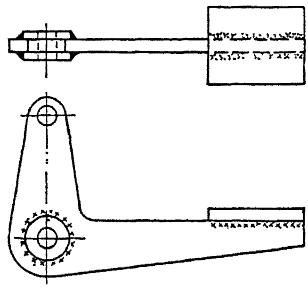


Fig. 613.

There are many different types of foot levers and pedals. Perhaps the first type of pedal that comes to mind is that used on automobiles for operating brake or clutch. This very common type is also used on various machines. Welded steel construction lends itself to the peculiar shapes required for foot levers or pedals (see Figs. 608 and 609).

The foot lever, (Fig. 610) a modification of lever previously shown consists of a plate mounted on top of a T-section, welded to a short piece of tubing. It may be further modified by adding a plate for additional strength and stiffness (see Fig. 611).

The design of Fig. 611 may be simplified by using fewer parts, (Fig. 612). Plates are shaped to the desired dimensions and assembled as indicated.

A lever for a broaching machine, (Fig. 613) is made up of a plate cut to shape and size, two bosses, and foot plate welded to the lever arm itself. This is a relatively simple lever and it has good appearance. Rounding the corners may improve further the appearance.

Another type of lever (Fig. 614) consists of a rather long, heavy plate cut to shape and size. Through its center is a bearing or boss applied as discussed previously. On each end of the lever arm is placed a smaller plate for a foot pedal. This, a very effective lever permits a certain amount of variation in the dimensions so that it may be fitted to the limits of the machine.

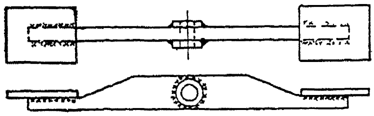


Fig. 614.

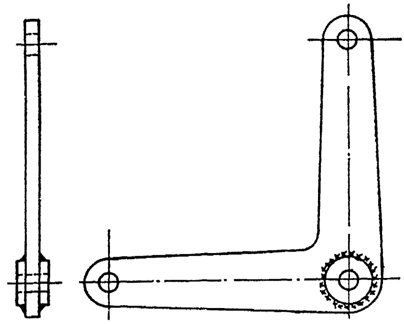


Fig. 615.

A bell crank, very similar to the lever shown in Fig. 613, is illustrated by Fig. 615. It may be cut out of plate to size and shape and bosses applied.

A rather simple lever arm (Fig. 616) consists essentially of bars joined together by welding, giving a rather neat appearance and fairly good strength. The wide supports at ends may throw bending into the center piece and it may be necessary to stiffen this.

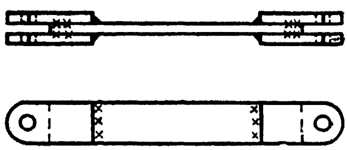


Fig. 616.

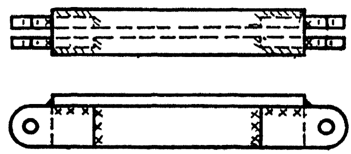


Fig. 617.

This may be done by a T-section for the connection of these end pieces, or another bar on top of the connection to give an effect of T-section, see Fig. 617.

The modification of the details shown indicates very clearly the ease with which changes may be made to meet the different design requirements.

Interesting details of arc-welded construction of levers are shown in the operating mechanism of a large butterfly valve (Fig. 618) built for installation in the piping arrangement of gas making machinery.

The upper arrow in Fig. 618 points to a more complicated form of lever than discussed previously. It consists of one piece shafting and four pieces of rolled steel plate (Fig. 619). The piece of shafting is drilled and keyed to fit the valve shaft. The plates, welded together forming the two arms of the lever, are slotted at one end and machined at the other end to fit the shafting, then welded to the shafting to form a lever with two parallel arms with open slots.

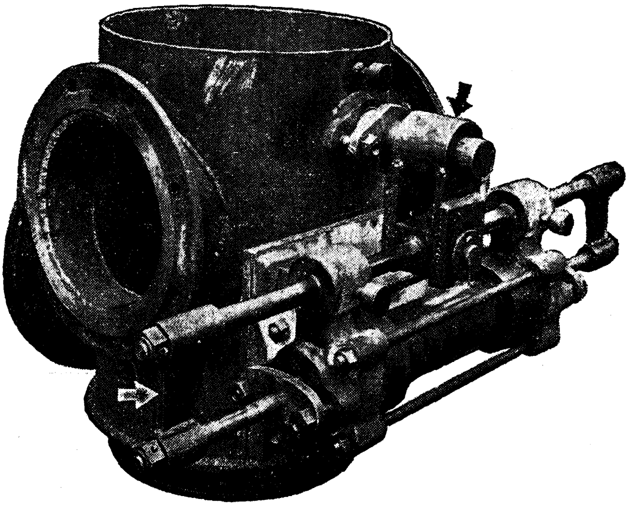


Fig. 618.

Fig. 618 shows a pin operates in the slots in the levers' arms. The pin moves in straight line in a horizontal plane, consequently up and down in the slots of the arms of the lever. The shaft through the top part of this lever connected thereto by a key, which results in the transmission of a reciprocal motion of the operating mechanism to a circular motion of the shaft. To obtain sufficient bearing surface

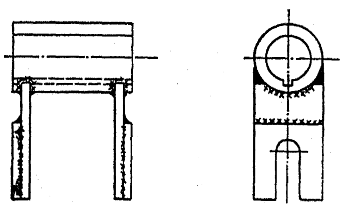


Fig. 619.

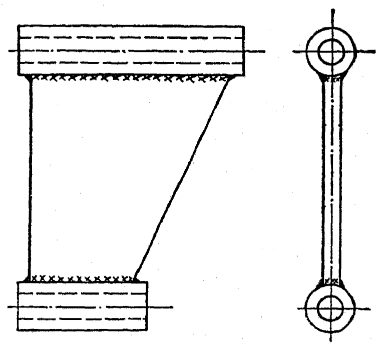


Fig. 620.

at point of contact of the pin with the lever, two plates are welded together.

Another detail (Fig. 618), consists of two pieces of round bar stock drilled, and a piece of plate; the three parts being arc welded together, (see Fig. 620).

Clevises and Pins.—Clevises often used with pin connections in lever mechanisms may have screwed connections as a means of adjustment for the leverage system. Usually forged or cast clevises have

screwed connections. When provision for adjustment of the lever mechanism is not required a forged or cast steel clevis may be easily arc welded to a lever without machining operations of drilling, reaming and threading either clevis or lever for the connection. A typical connection of clevis with lever is shown in Fig. 621. Another advantage of the arc-welded connection is that the lever bar may be smaller in section because its effective sectional area is not reduced, no threading being required for the arc-welded connection, Fig. 621. A saving in material and weight is thereby effected.

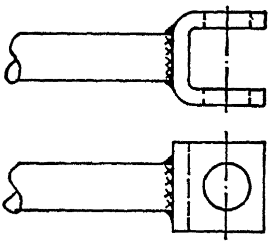


Fig. 621.

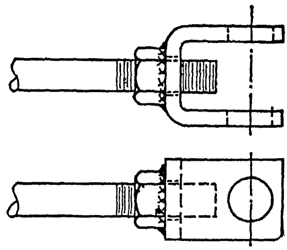


Fig. 622.

A clevis may be formed by bending a piece of flat bar stock into U-shape (Fig. 621). A threaded connection to the lever bar may be provided without drilling, reaming or threading by the simple expedient of welding a nut to the bottom of the clevis, (Fig. 622) which drilled (not threaded) to allow extensive adjustment of length of lever.

Two pieces of plate, parallel, on opposite sides of a lever bar of round or flat sides form a simple clevis. The welds, placed as indicated in Figs. 623 and 624, illustrate an important fundamental: i.e., welds should be placed transverse to direction of lines of force where possible, as they are stronger in this position; however, where it is impossible to so place the welds, they may be placed parallel to lines of force but should be of larger section or longer than required for transverse welds (see Page 66).

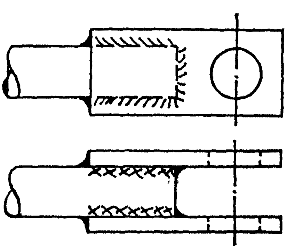


Fig. 623.

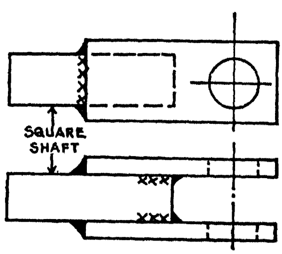


Fig. 624.

Types of clevises similar to the one in Fig. 623 are illustrated in Figs. 616 and 617. Where clearances will permit, it is unnecessary to round the corners of the wings or legs at the open end of the clevis. Improved appearance is obtained but at an increase in production cost.

Another design of clevis (Fig. 625) consists of three pieces of plate assembled and welded. If a threaded connection with lever bar is desired the center piece of the clevis may be a nut.

Pins for connections in leverage systems may be made by arc welding a head to a piece of round bar stock. Varied types of pins can be made in this manner. A bar welded to one end of a round bar (Fig. 626) is adapted for use where service is not heavy.

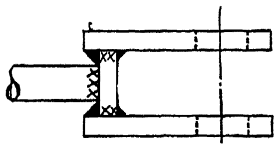


Fig. 625.

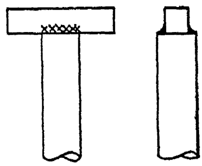


Fig. 626.

Another type of pin, a heavy washer welded to a round bar for a head is illustrated in Fig. 627.

A third type for heavy service, employs an oversize nut as a head.

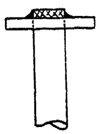


Fig. 627.

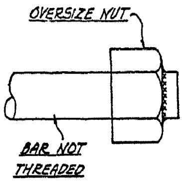


Fig. 628.

(See Fig. 628.) The nut should be of such size as to slip over the bar which is not threaded.

Crankshafts.—A rapid, inexpensive method of making crankshafts is available through the use of arc-welded construction. The following examples demonstrate the flexibility of this type of construction.

An extended crank (Fig. 629) consists of two pieces of shafting welded together. This may be machined as shown in Fig. 630.

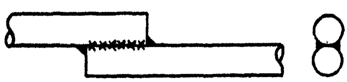


Fig. 629.

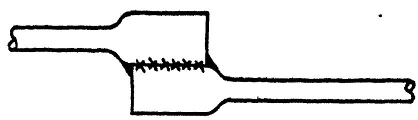


Fig. 630.

A crank between two bearings is indicated by Fig. 631. A crank of multiple throws is shown in Fig. 632.

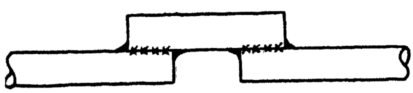


Fig. 631.

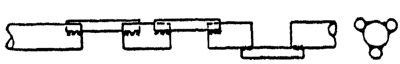


Fig. 632.

Where a greater throw is required a piece of plate may be used as the connecting member between the pieces of shafting, (Fig. 633). Fillet welds only may be used as shown or the crank plate may be drilled to receive the shaft and the joint thus formed welded.

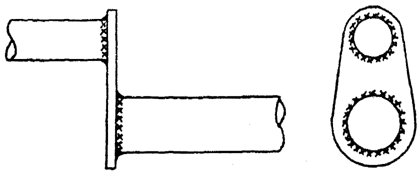


Fig. 633.

An arc-welded crankshaft of the type illustrated by Fig. 633 is shown in the photograph, Fig. 634. The application of this same crankshaft to a triple gate valve mechanism is also shown.

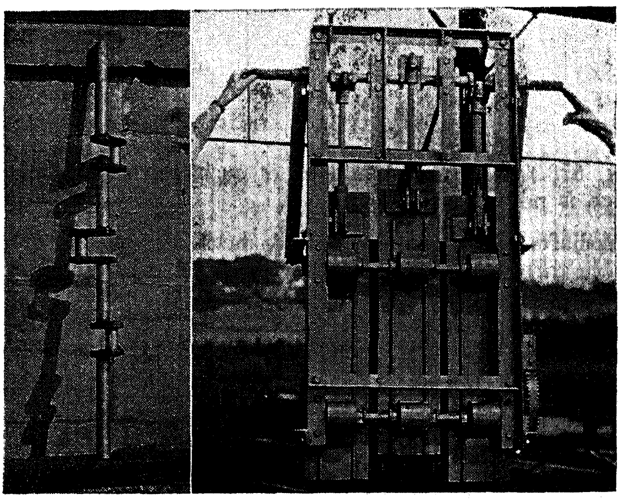


Fig. 634.

Where counter balance is required, the crank plate may be so shaped in regard to area and weight distribution, to give the required counter balancing. Additional weight may easily be added by welding required additional material to the crank plate (Fig. 635). Exact weight then can be obtained by depositing weld metal on the crank plate.

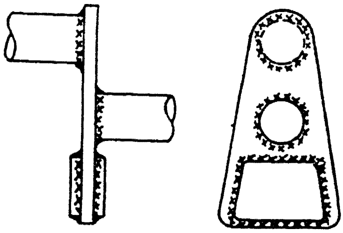


Fig. 635.

From the brief suggestions, the possibilities of arc-welded crankshaft construction may be easily visualized. With this method of construction only a few stock parts are required for making a great variety of crankshafts, for low cost and minimum expenditure of time.

Cams and Eccentrics.—As a further illustration of the simple parts which can be made of steel, a cam, eccentric and gear arm brackets are shown.

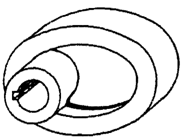


Fig. 636.

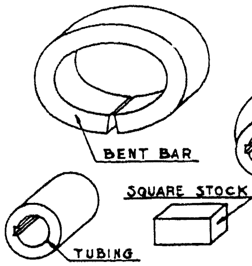


Fig. 637.

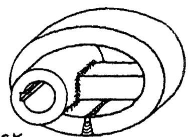


Fig. 638.

At first glance the cam of Fig. 636 it may look difficult to make of welded steel. A little study shows that the cam is an assembly of parts—those shown in Fig. 637: a piece of bar stock, properly shaped

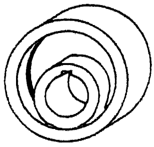


Fig. 639.

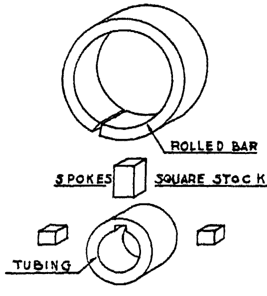


Fig. 640.

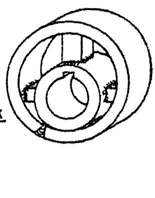


Fig. 641.

and welded, a piece of tubing with a keyway cut in it for the shaft, and a smaller piece of bar stock to hold the parts in place. These parts joined together make the completed welded steel cam shown in Fig. 638.

With the cam as a starting point, it is easy to make the eccentric (Fig. 639) of arc welded steel—the same way as the cam—from standard steel parts. The parts (Fig. 640) are a piece of bar stock, rolled and welded to form the outside ring (as in the case of the cam), a length of standard tubing, cut and slotted for the keyway, and three pieces cut from bar stock for spokes assembled and welded together, make the completed cam shown in Fig 641.

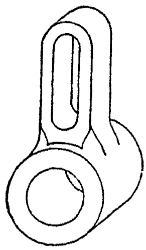


Fig. 642.

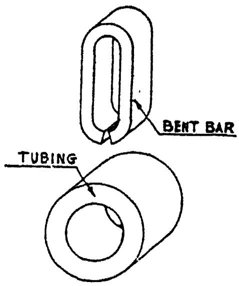


Fig. 643.

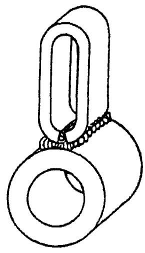


Fig. 644.

A part requiring two internal contacts, instead of an internal and an external as in the case of the cam and eccentric, is the compound gear arm shown in Fig. 642. The method of making the arm is the same as for the cam and eccentric. Standard materials (Fig. 643) a bar cut, bent and welded to form the link, and a piece of tubing for the circular support welded together, make the completed steel gear arm (Fig. 644).

The cam, eccentric and gear arm are assemblies composed of bar stock and tubing. These, the simplest of elements, are what arc welding starts with.

Brackets.—The purpose of a bracket may be to serve as a direct support for load, or it may involve a rather complicated arrangement, of loading.

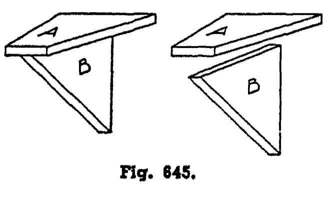


Fig. 645.

A simple bracket (Fig. 645) has two parts—a support at the point of load application, (shelf A), and a stiffener member underneath (part B). This type of bracket is suitable for a direct load of rather low value.

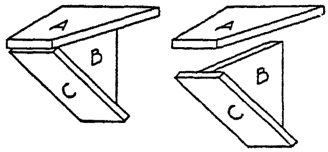


Fig. 646.

A bracket (Fig. 645) suitable for somewhat heavier loads is made by using a member of the type shown at lower right, Fig. 646, in place of member B, Fig. 645. This is composed of two plates B and C to form a T section. A bracket of this type provides a considerable increase in stiffness over the type shown in Fig. 645 and is used for supporting a direct load acting downward.

The brackets shown in Figs. 645 and 646 are used extensively in more or less simple applications in machinery construction. Load conditions in machines are usually more complicated.

In applications where some loading thrust is at right angles to the web, the requirement is met in either of two simple ways: Either the plate A in Fig. 645 is made wider or plate C in Fig. 646 is used. The latter method provides greater resistance to the loading conditions mentioned.

A bracket suitable for taking care of both side thrust and downward

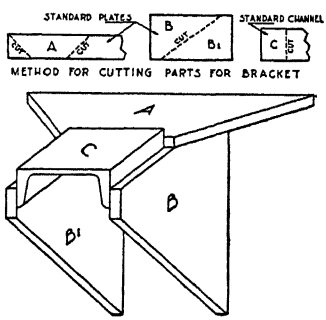


Fig. 647.

thrust is shown in Fig. 647. The former is taken by plate A and the latter by the two plates B and B_1. Members B and B_1 may be T sections as in Fig. 646.

Fig. 647 shows how simply the bracket is made by welding. Members A, B and B_1 are cut to desired size from standard plate of required thickness and welded to the supporting surface. Member

C is a channel cut to proper length. Then the surface of C is located and C is welded in position. This type of construction allows C to be moved in or out, or up and down, to permit adjusting dimensions so they bear the correct relation to the other parts of the machine to which A, B, B_1 and C are attached. (Note: All these parts are square cuts as shown top Fig. 647).

Fig. 647 illustrates a plan for making a bracket to meet given load conditions. The bracket shown is by no means the limit of possible arrangements. Parts A, B and B_1 may be flanged, part C may be in one piece, as a channel, or several pieces welded together.

A considerable variety of combinations of parts can be worked out for making brackets due to the flexibility of arc welded assembly and the ease it permits in making adjustments.

Fig. 648 shows an operating rod. Note the easy lines, the rather gradual change from one section to another; and how the support and load are connected together.

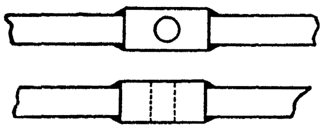


Fig. 648.

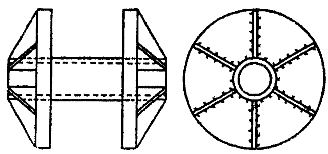


Fig. 649.

The reel (Fig. 649) is made up of a tube and end plates with ribs or stiffeners so placed that when considerable pressure comes on the outside or rim of the flanges, this reel is wound up with rope or cable, the stiffeners are in position to take this thrust. They are in direct line connecting the point of application of the load with the point of support. The boss of Fig. 650 is placed on the web of the channel

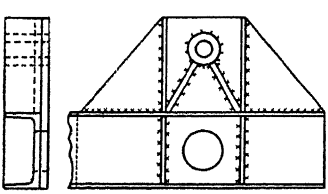


Fig. 650.

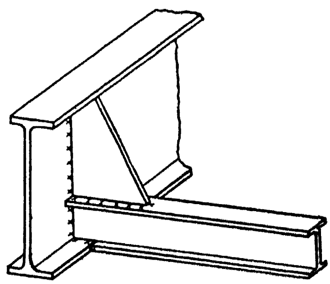


Fig. 651.

and this channel is supported by another channel, the vertical channel ribs carried straight through to the final point of support. Cross bracing is obtained by the use of the plate. Due to the position of the hand hole, it was necessary to bring the points of support over to the side as shown by the plate.

Fig. 651 shows how a stiffener effect may be continuous through a member. A plate and the web of the smaller I-beam are so combined that there is no interruption in the lines of force.

Assembly of Welded Parts.—Sub-assemblies and complete assemblies of a variety of welded machine parts are shown on the following pages. These examples illustrate how easy it is to fabricate by welding. They show the high degree of designing freedom made possible by the variety of available shapes and sections. They illustrate how load and service requirements may be met readily with designs which are of relatively light-weight, rigid construction and pleasing appearance.

These examples are details of actual machines, formerly of cast iron construction, which have been designed for welded steel fabrication.

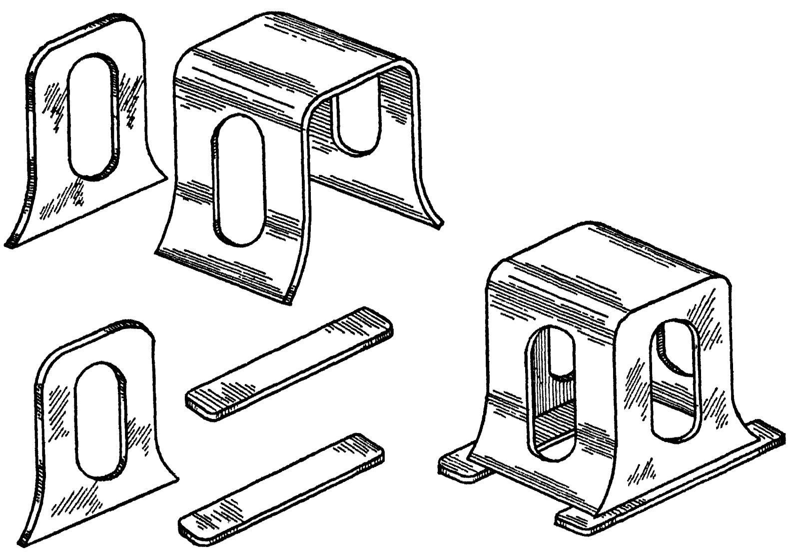


Fig. 652. A pedestal of good appearance. Note the simple box-like construction and how readily additional ribs may be placed.

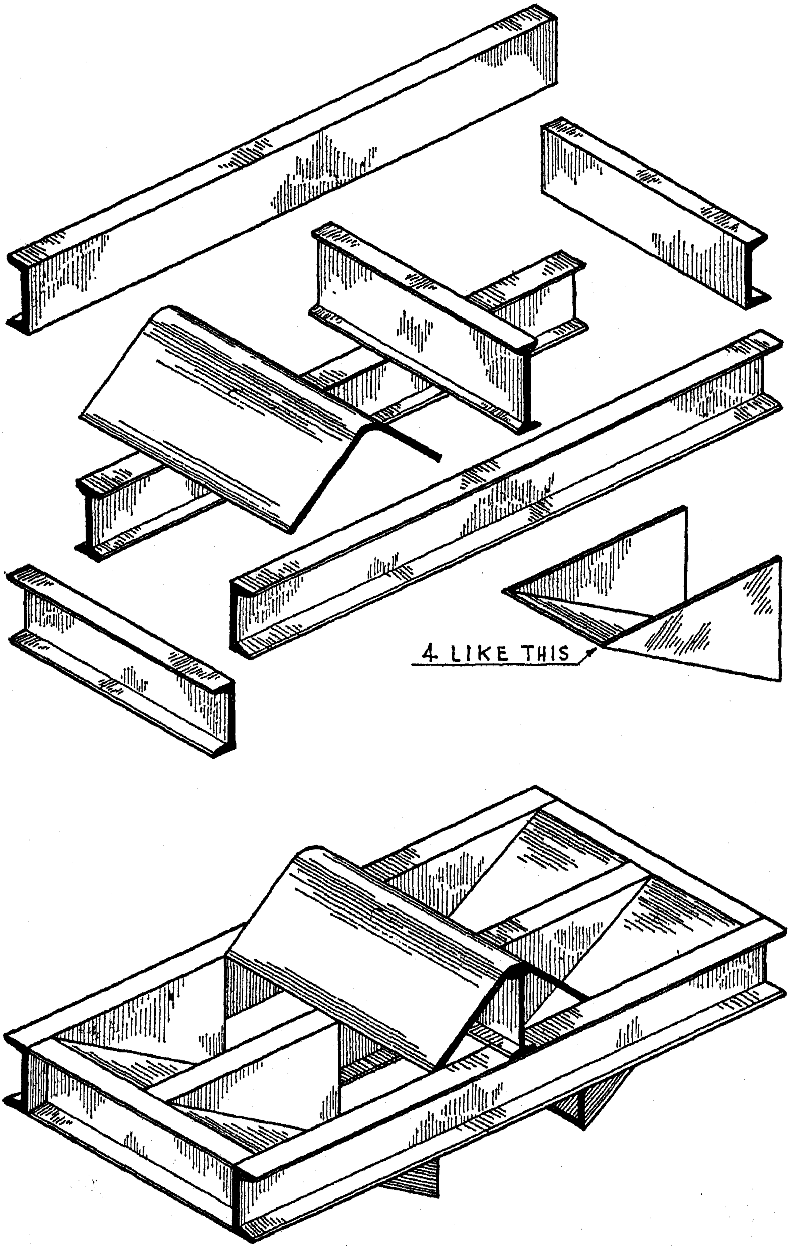


Fig. 653. A multiple hopper made from channels, I Beams and plate. At first glance it might seem complicated, but it really consists of just a few simple parts.

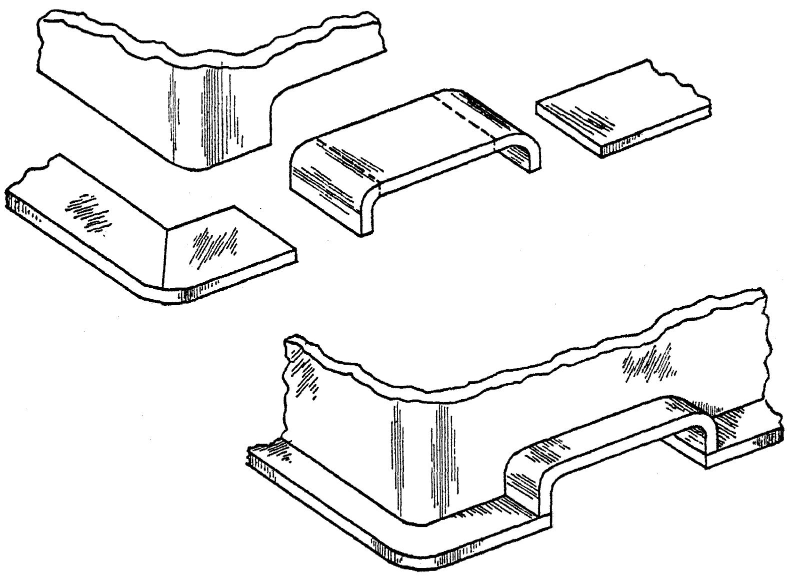


Fig. 654. A study in styling by welded design, showing how round corners and grooves may be secured where desired. The design is extremely simple and inexpensive.

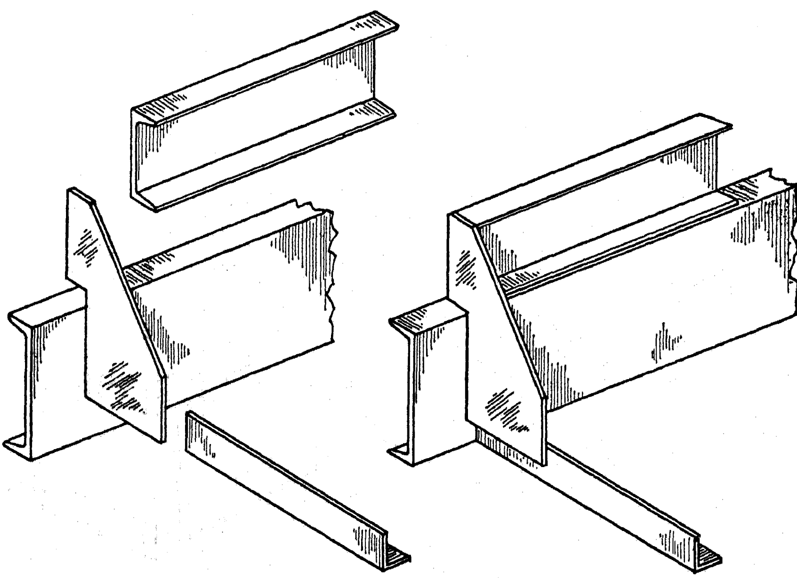


Fig. 655. A corner detail where lightness, stiffness and strength are very important. Note the box-like construction of the entire assembly of standard rolled steel shapes.

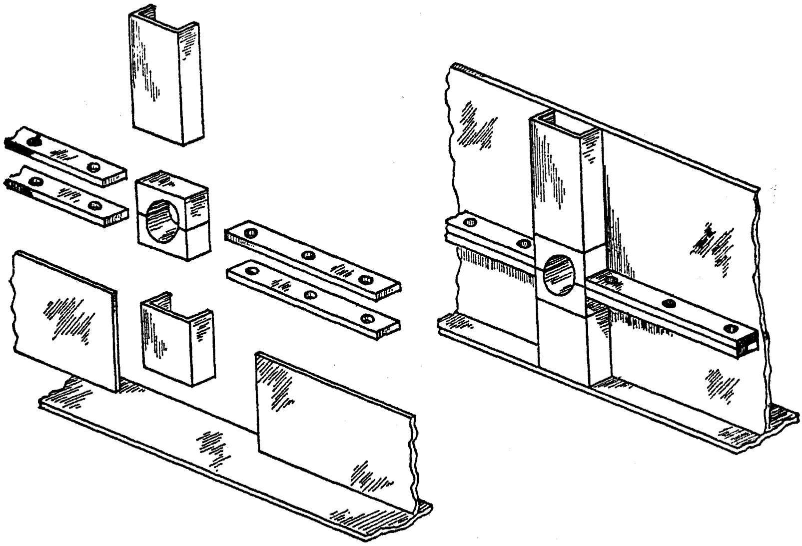


Fig. 656. A bearing block support and auxiliary arrangement. The block is supported by a channel section and the same channels afford effective stiffness for the side plate.

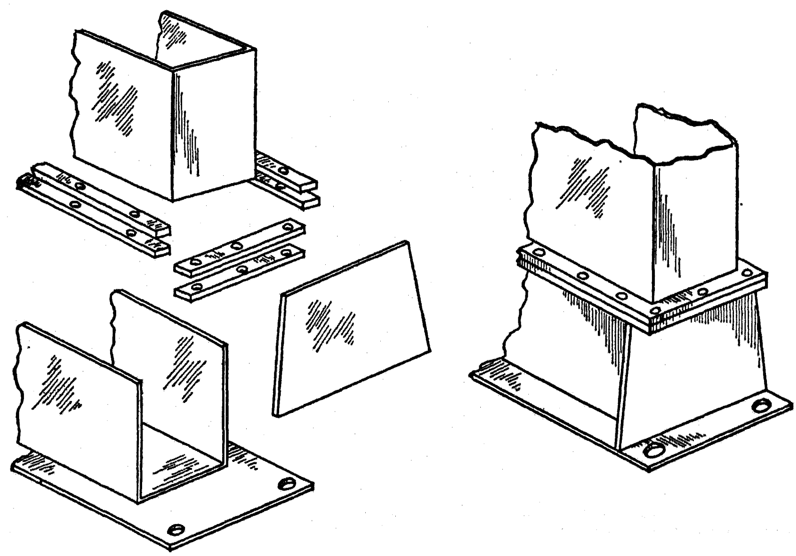


Fig. 657. An enclosure for a mechanism. The upper and lower parts are folded together to afford access. The design is extremely rigid and of low cost because of the use of standard rolled steel shapes.

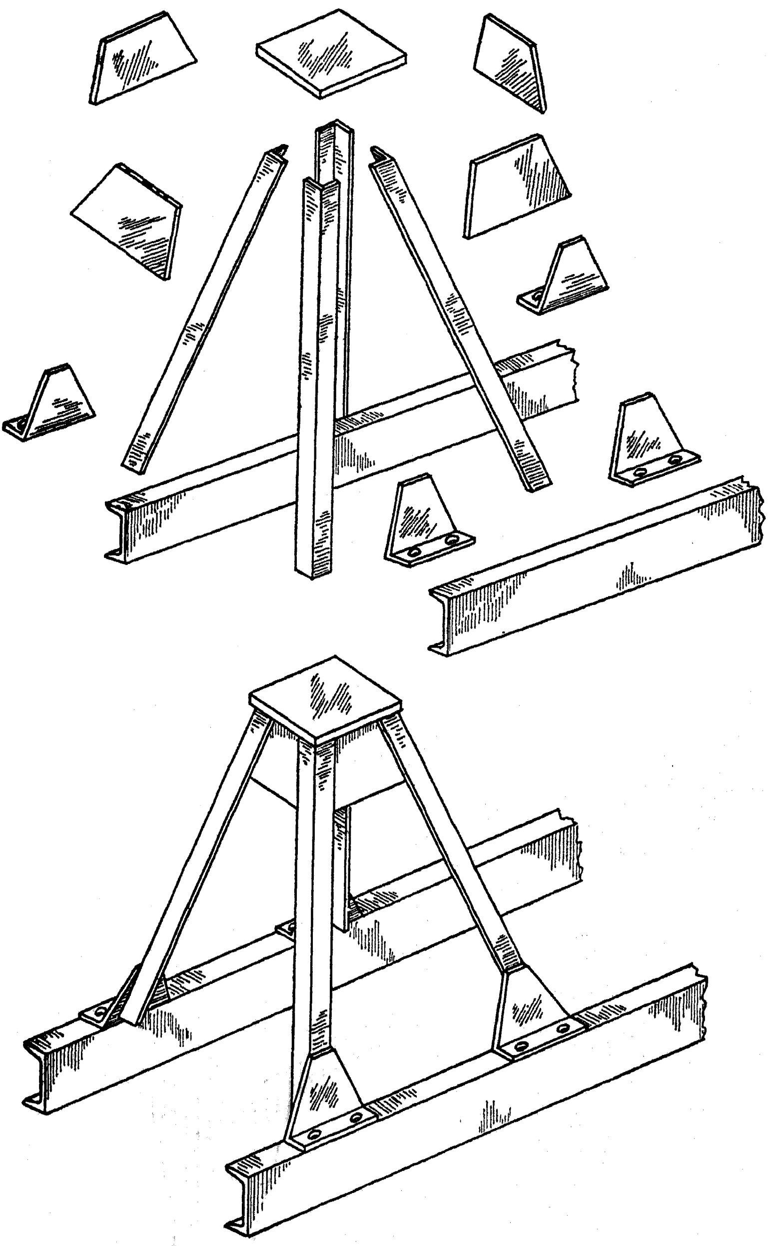


Fig. 658. A support for a bearing which requires considerable clearance beyond it. It is bolted to the base for maintenance purposes.

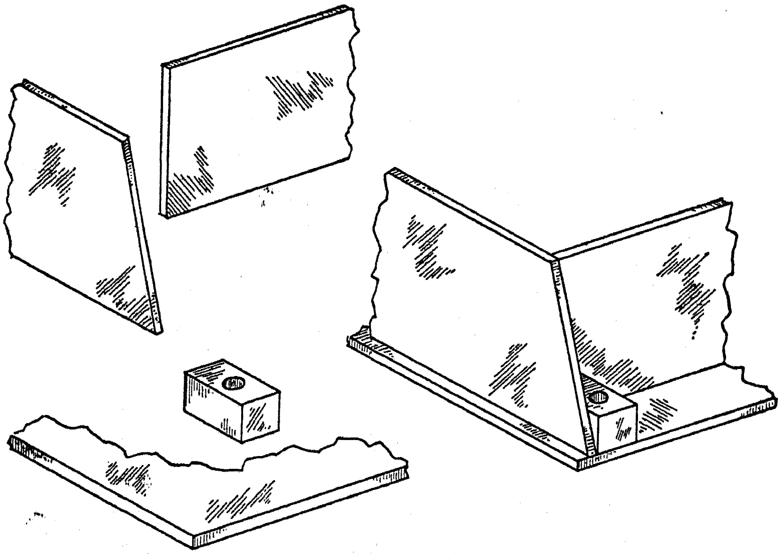


Fig. 659. A base corner with a boss for holding-down bolt. An extremely inexpensive design. Easily assembled, with no scrap material.

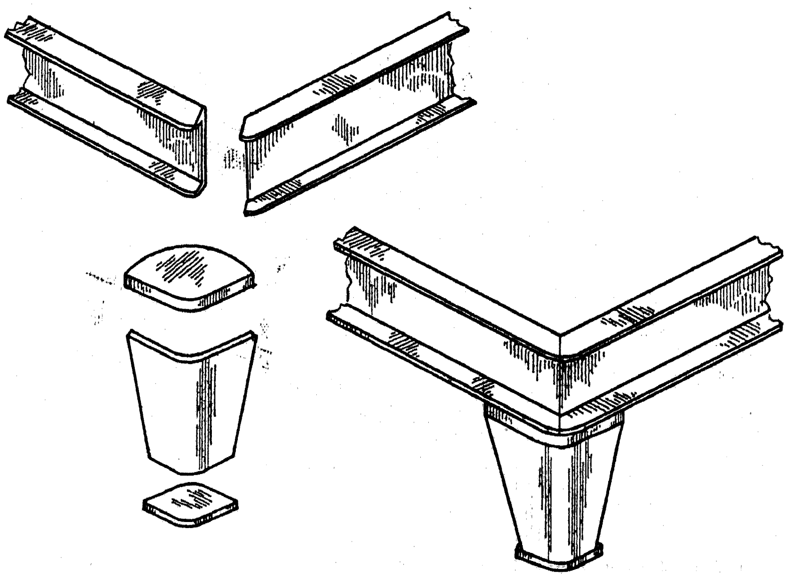


Fig. 660. The corner of a supporting member where a simple rounded design is required. The construction has minimum weight with maximum strength.

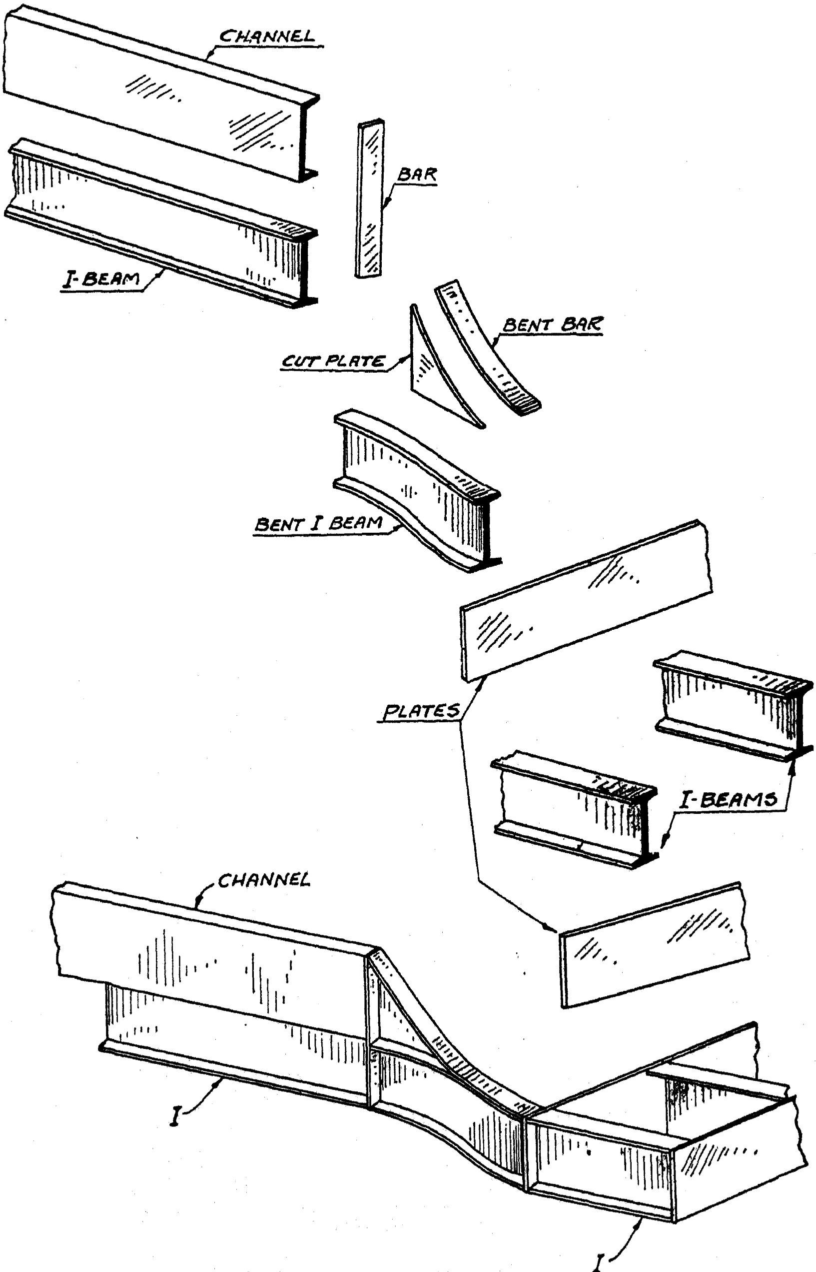


Fig. 661. A base design in which two machine parts are to be mounted at different elevations. This construction is highly economical and effective.

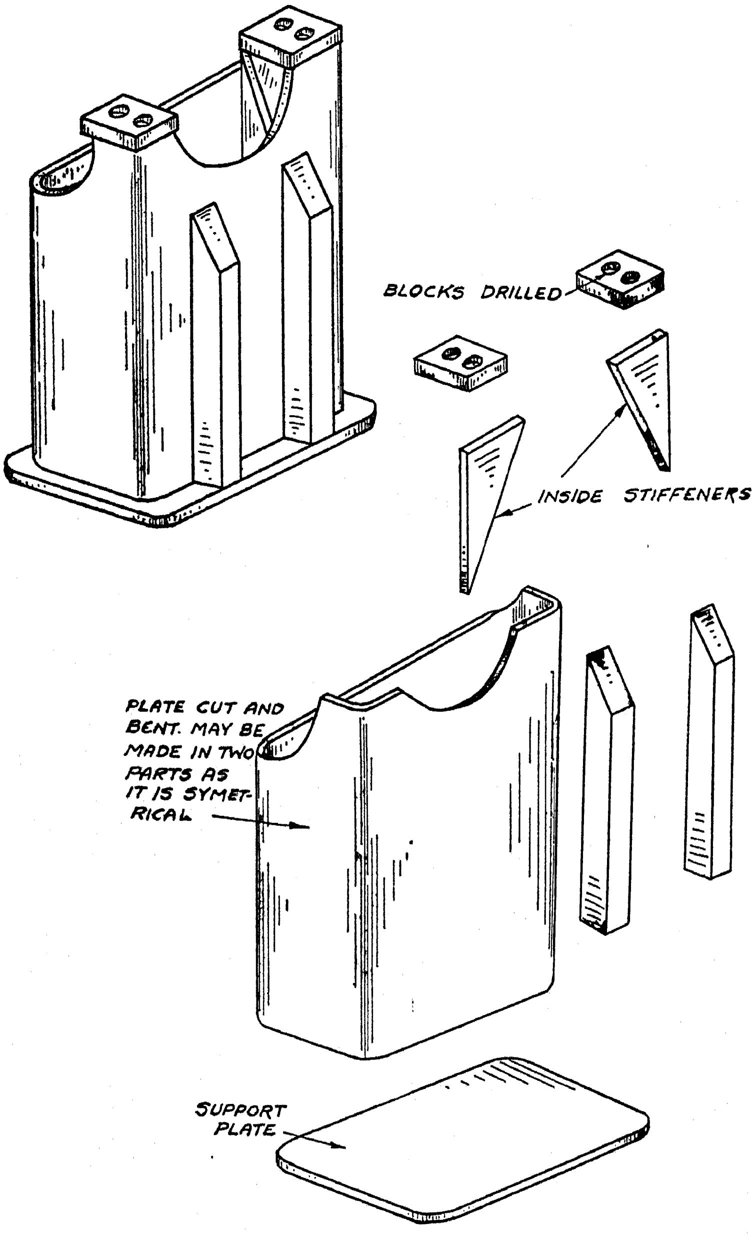


Fig. 662. A base for an operating mechanism which extends down beyond the base into the semi-circular opening shown. The bars on the outside serve as stiffeners and also can be drilled and tapped for adjustments on inside of base.

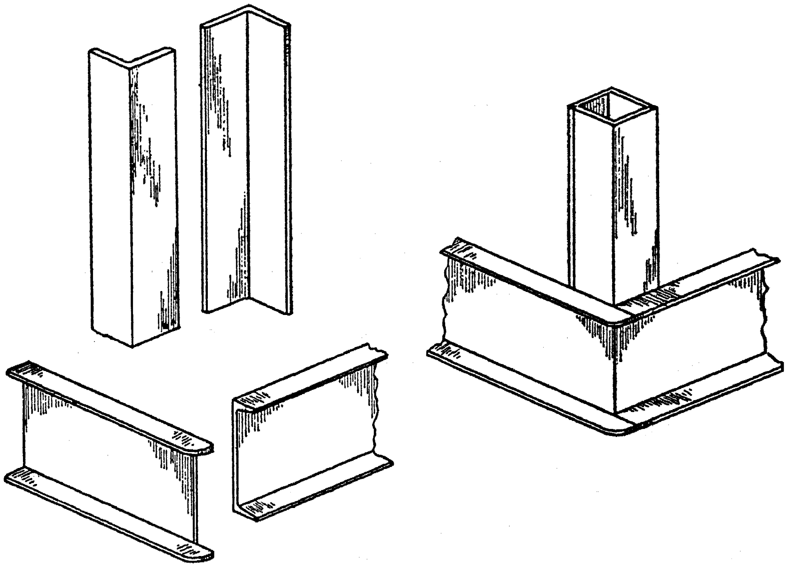


Fig. 663. Using angles and channels a corner design can be made to give an extremely stiff construction for vertical load.

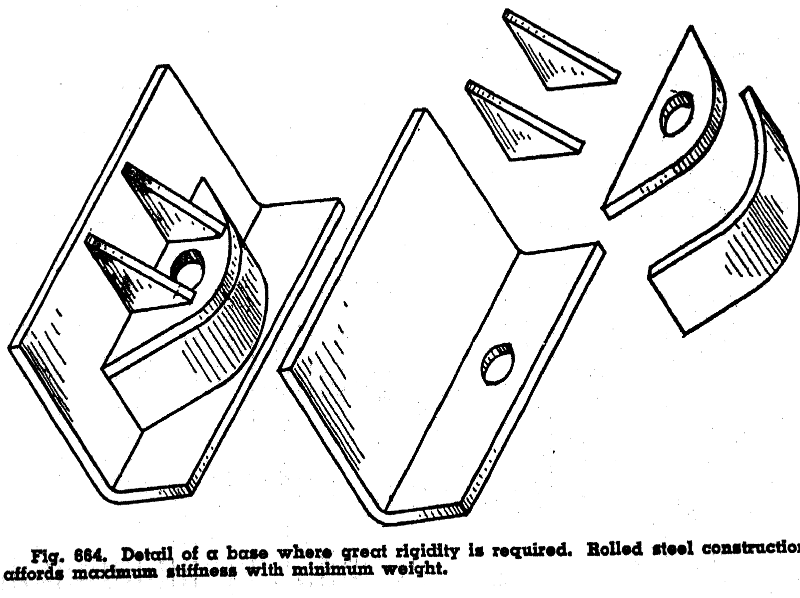


Fig. 664. Detail of a base where great rigidity is required. Rolled steel construction affords maximum stiffness with minimum weight.

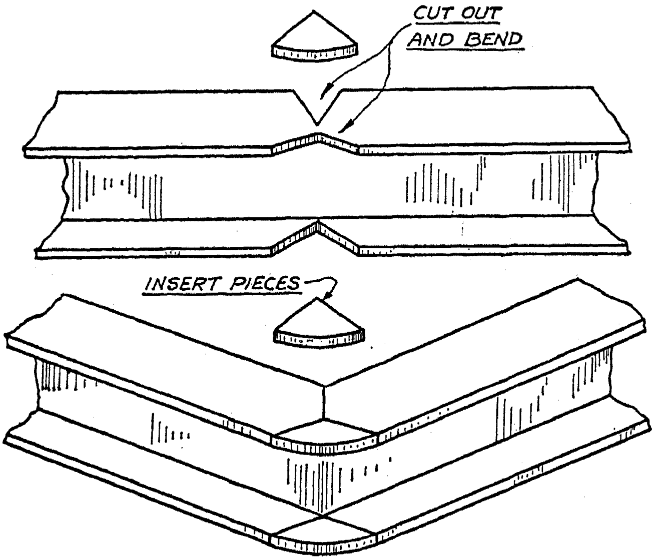


Fig. 665. A method of securing a round corner on an I beam base through the use of flame cutting and arc welding.

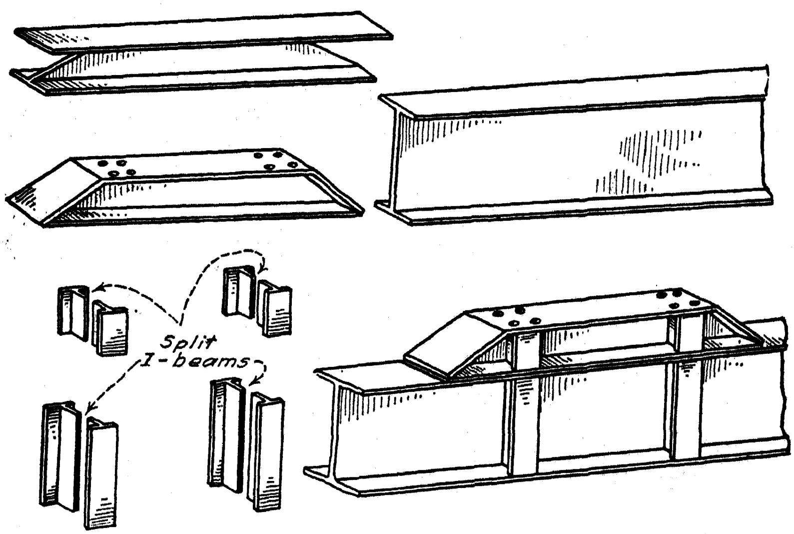


Fig. 666. Where loads are heavy and substantial column support is required, this design is effective and economical. The top member is made from an I beam with the web cut as shown. The stiffeners are smaller I beams split down through the web.

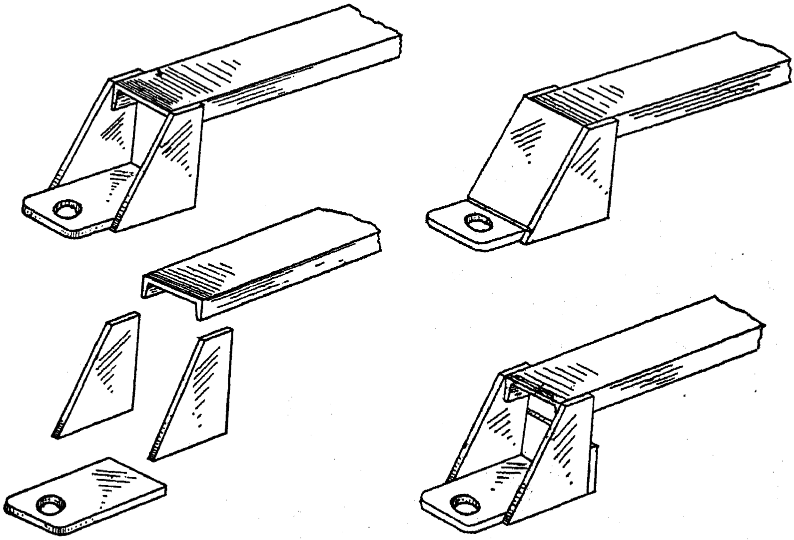


Fig. 667. A base detail. The design shown at the top can be given greater stiffness by the addition of a plate, either in the front or in the back as shown.

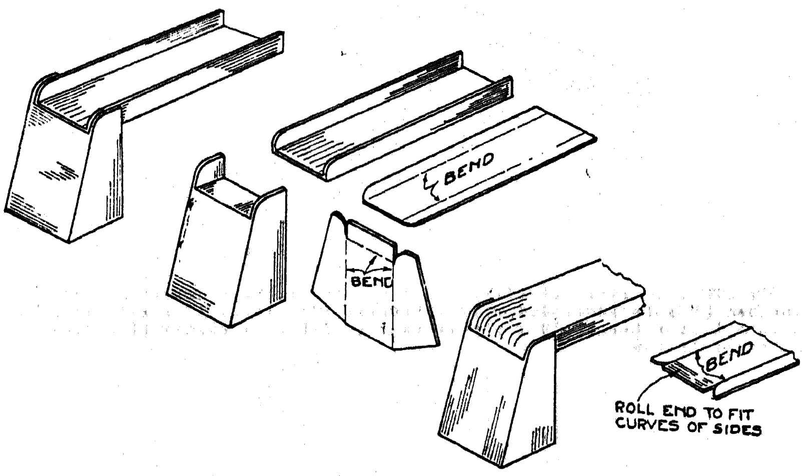


Fig. 668. A simple, light weight base design. (Only one end is shown.) The material is light gauge. This box like construction provides exceptional strength and makes possible a design which can be modified readily to suit the application. For example, it may be designed as shown at the right to provide a rounded surface for pleasing appearance.

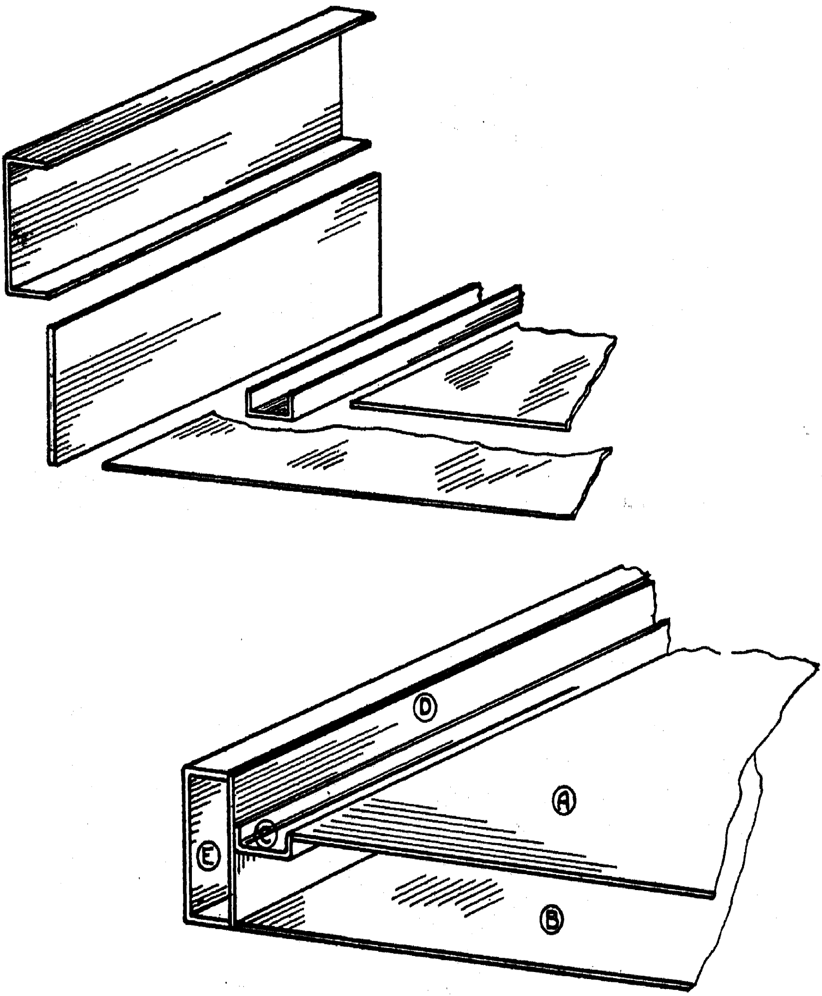


Fig. 669. Cross section of a base. (A) is a plate supporting member and top of oil chamber. (B) is the bottom plate of the support and oil chamber. (C) is a channel which forms a drain or trough. (D) is a plate which welded to the channel (E) forms a box section for the side.

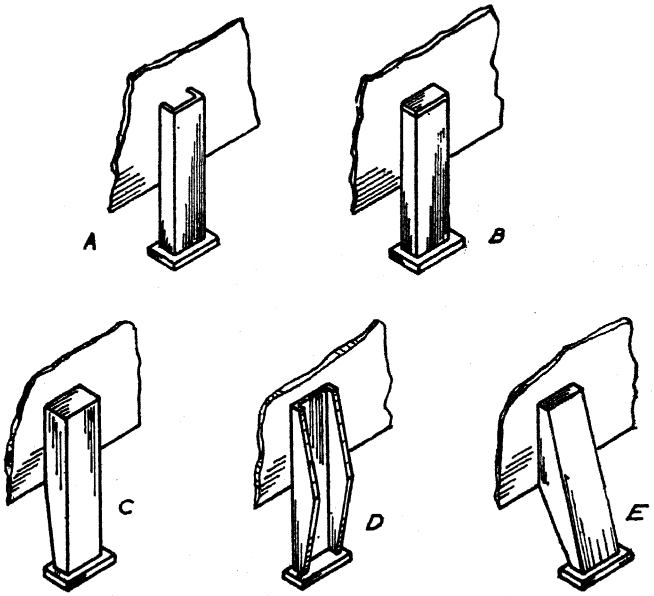


Fig. 670. An assortment of designs of a support column to be welded to the side of a machine. (A) is not a particularly pleasing appearance. A cap over the top of the channel as shown in (B) improves the appearance. Another approach, with a slight taper of the channel is shown in (C). In (D) both ends of the flanges are tapered. (E) shows the same design with the flanges turned inward.

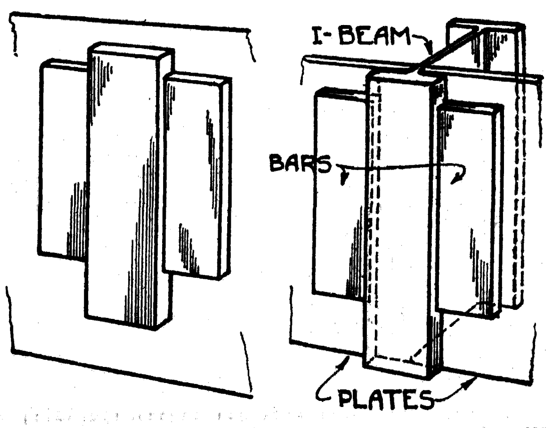


Fig. 671. This sketch shows how a functional design can be modified slightly for improved appearance. Functional design embodies an I beam structural member and plate siding. Streamlining effect is obtained by welding two bars to the plate alongside the flange of the I beam as shown.

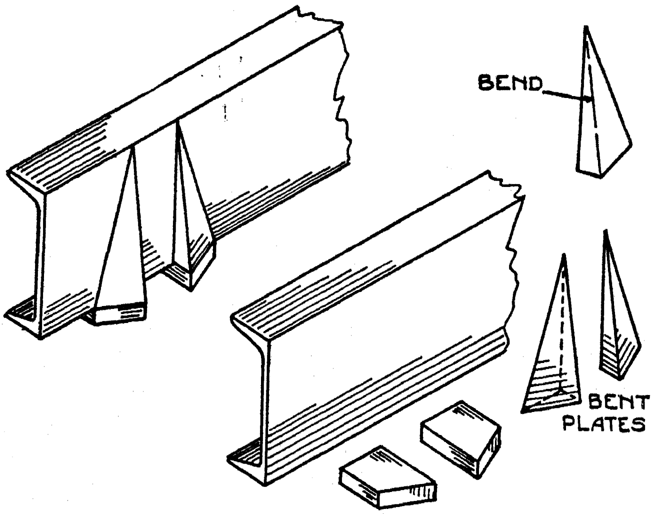


Fig. 672. A suggestion for improving appearance of a base detail. This low-cost refinement is obtained by cutting and bending bars and plates as shown and welding them to the web of the main channel member.

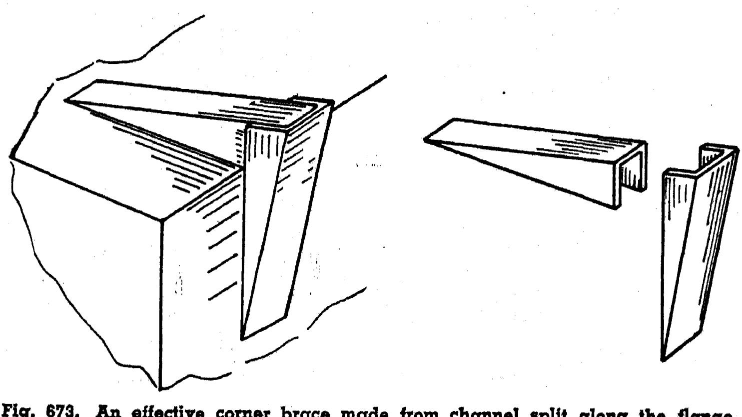


Fig. 673. An effective corner brace made from channel split along the flange into two tapered pieces for a low-cost design.

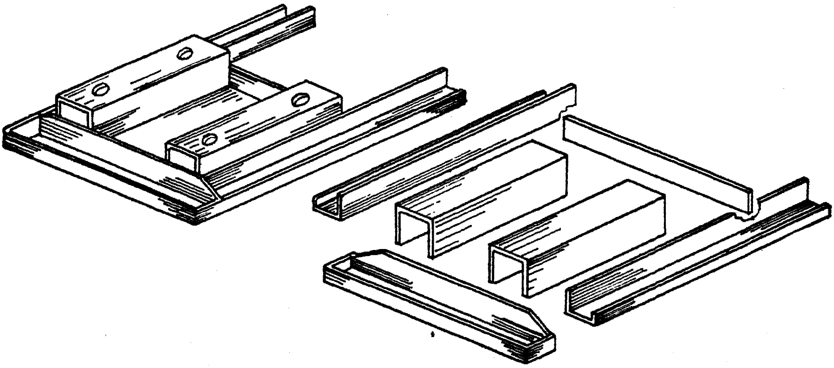


Fig. 674. Detail of the end of a base welded from formed plates shaped into channels for a rigid, light, strong construction.

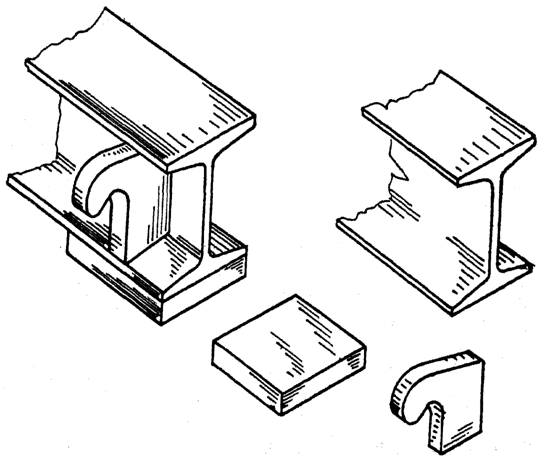


Fig. 675. Detail of a base corner showing how a lifting hook can be applied. Note the simplicity of this construction.

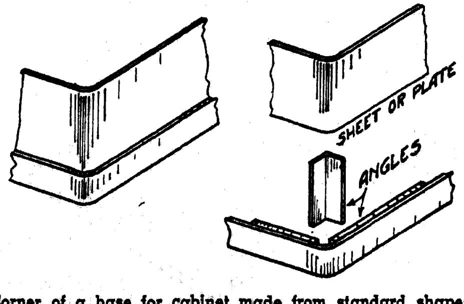


Fig. 676. Corner of a base for cabinet made from standard shapes and plate. A vertical angle provides an excellent stiffener so that the siding can be made from relatively light material for lower cost. The bottom rim is an angle with the flange cut out at the corner and rounded to shape.

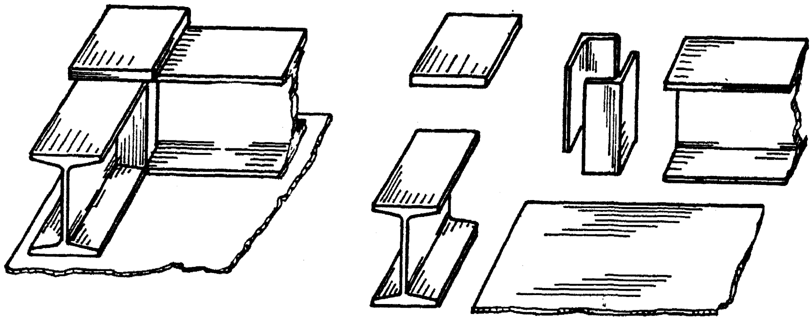


Fig. 677. A corner of a machine base made from plate and standard shapes providing a simple, rigid and substantial construction with minimum scrap loss.

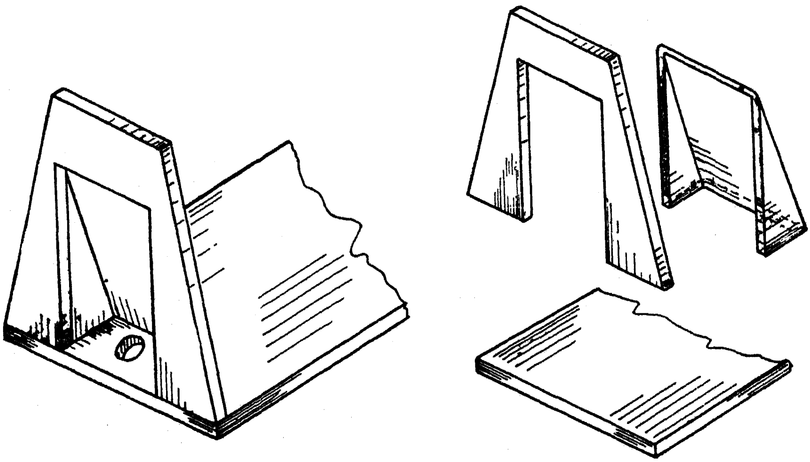


Fig. 678. Detail of end of base for holding down bolts where the latter must be readily accessible and where space is limited.

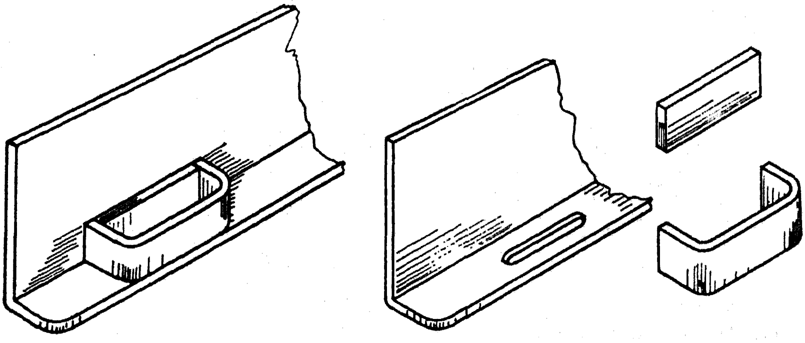


Fig. 679. Detail of a holding down bolt hole where some adjustment of the part is required. This provides a simple, low cost construction of pleasing appearance.

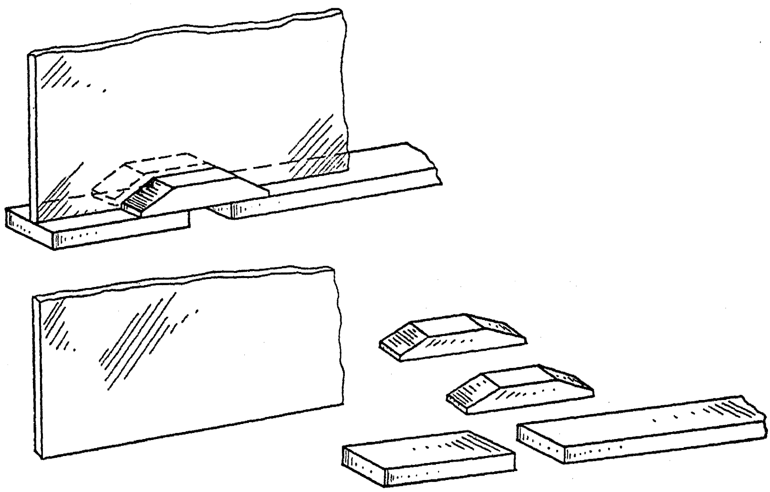


Fig. 680. Opening in a machine base for access with a pinch bar. There is practically no scrap.

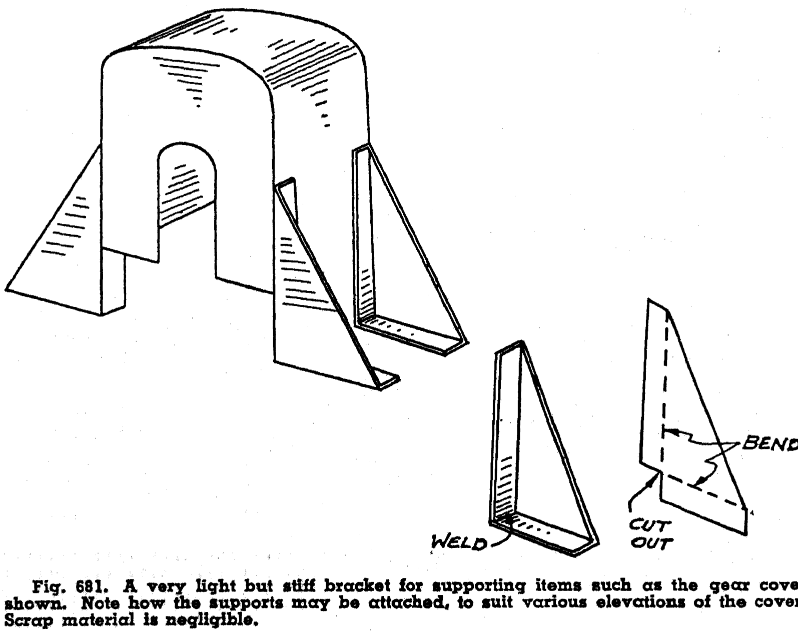


Fig. 681. A very light but stiff bracket for supporting items such as the gear cover shown. Note how the supports may be attached, to suit various elevations of the cover. Scrap material is negligible.

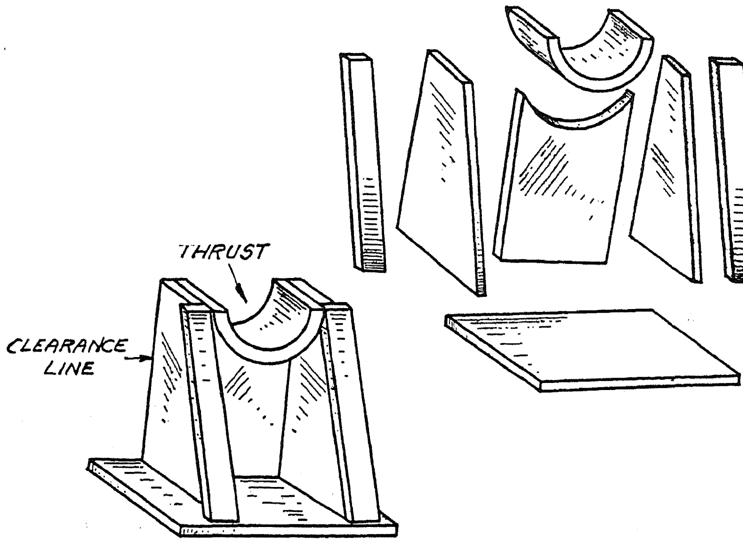


Fig. 682. A simple bearing bracket. End thrust is taken care of without the need for extension or projection beyond clearance line.

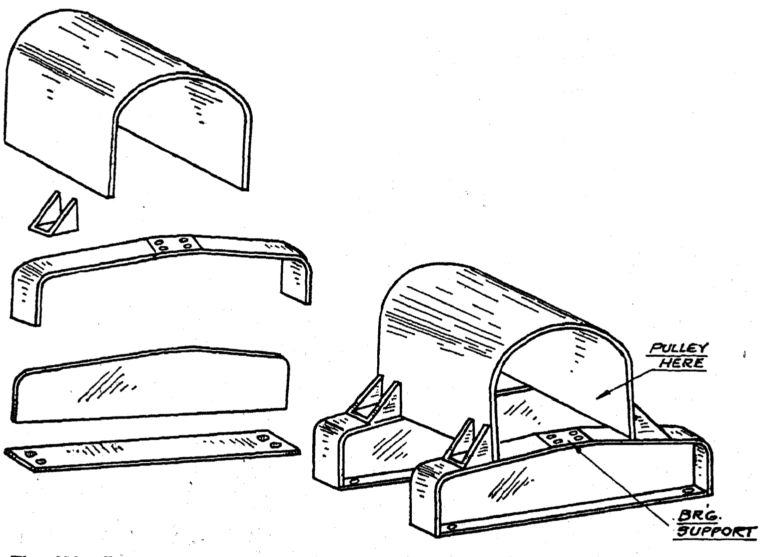


Fig. 683. A covered pulley support in which members are given round corners for the sake of appearance. The supporting bases are I sections made from bar and plate stock.

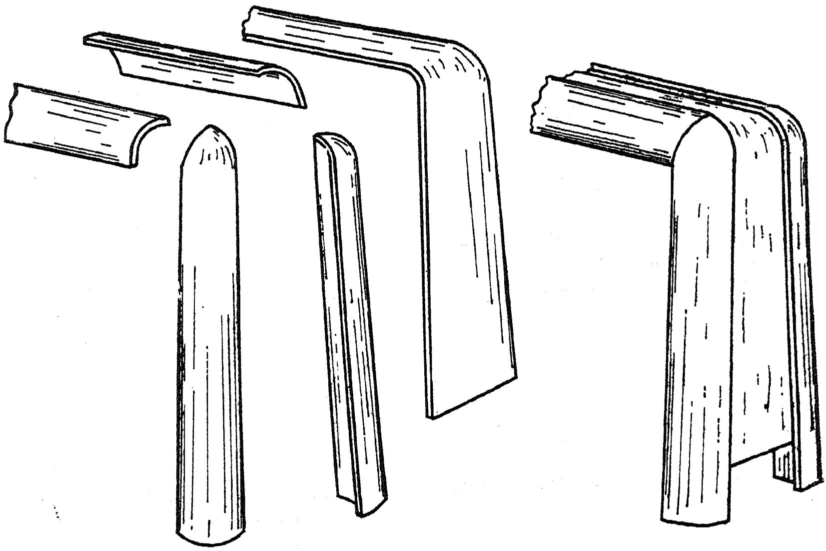


Fig. 684. Corner detail of a streamlined support. Pressed steel plates give pleasing appearance with the strength and stiffness of steel construction.

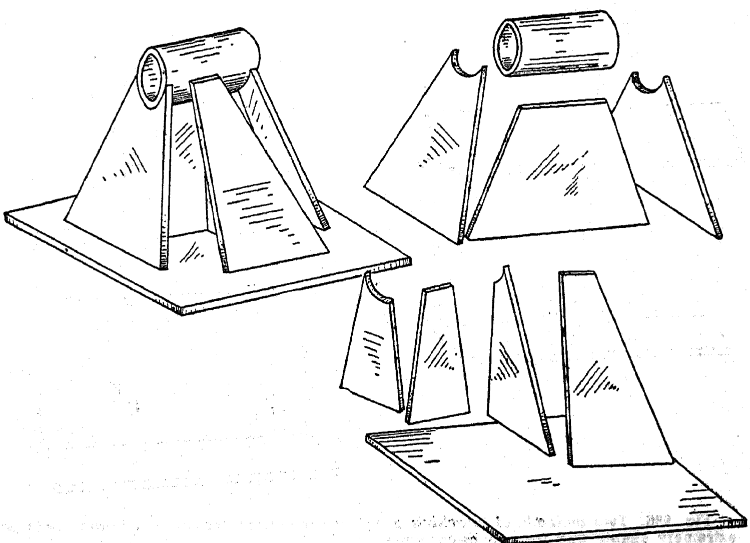


Fig. 685. A design for application of load such as a bearing. It provides stiffness in both directions comparable to the stiffness of an I beam.

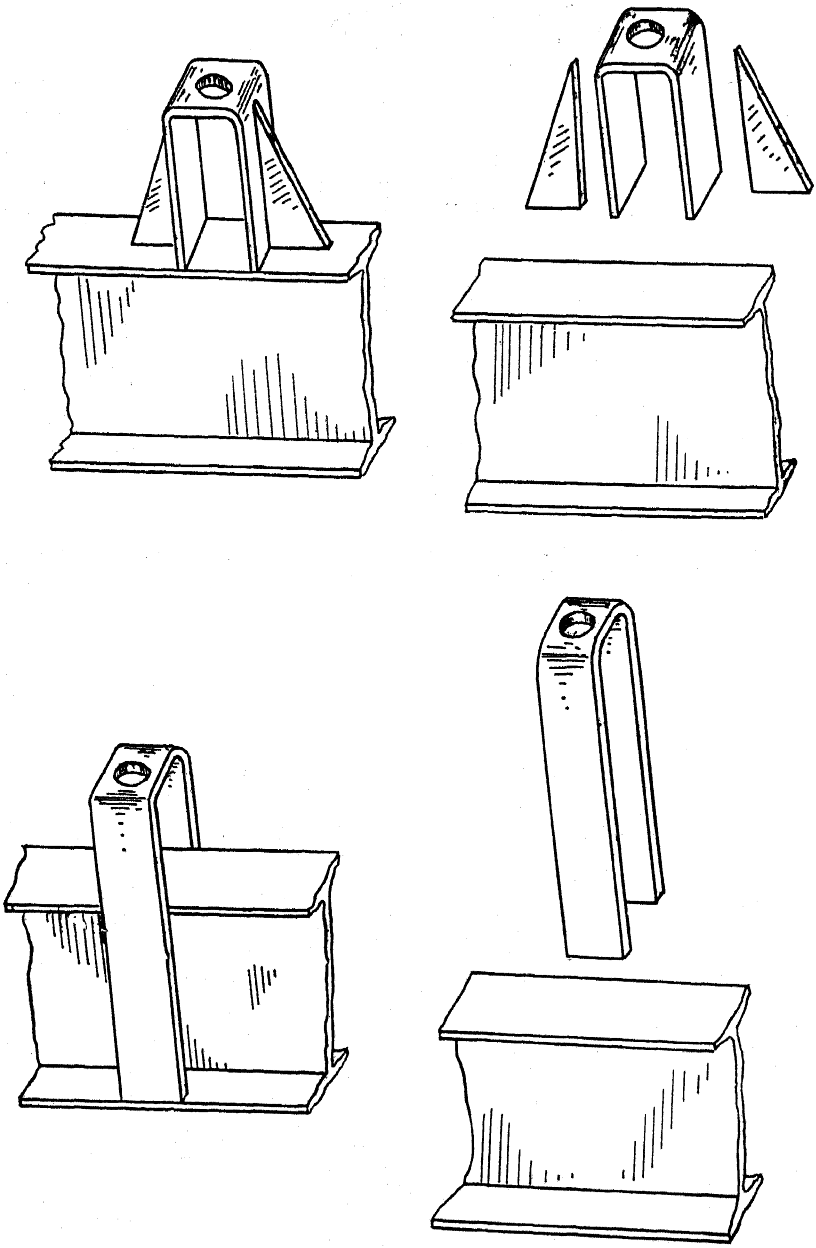


Fig. 696. Two methods of attaching a link for a tension rod to an I beam. Both are extremely simple and neat in appearance.

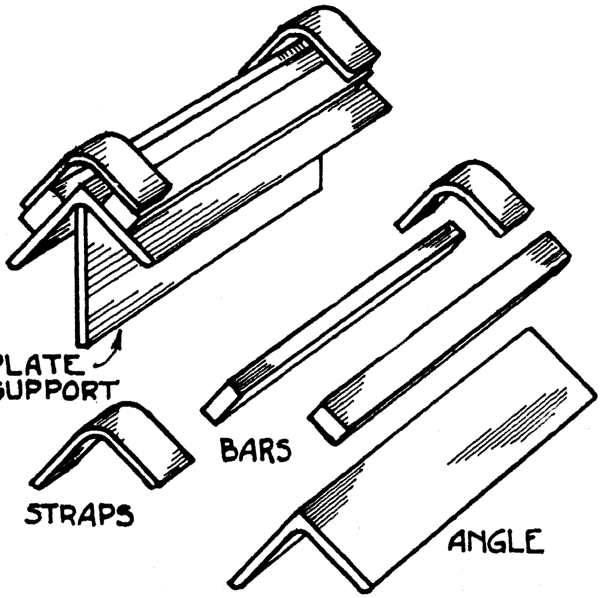


Fig. 687. Suggestion for a jig to be used for fit-up in welding of thin sheets.

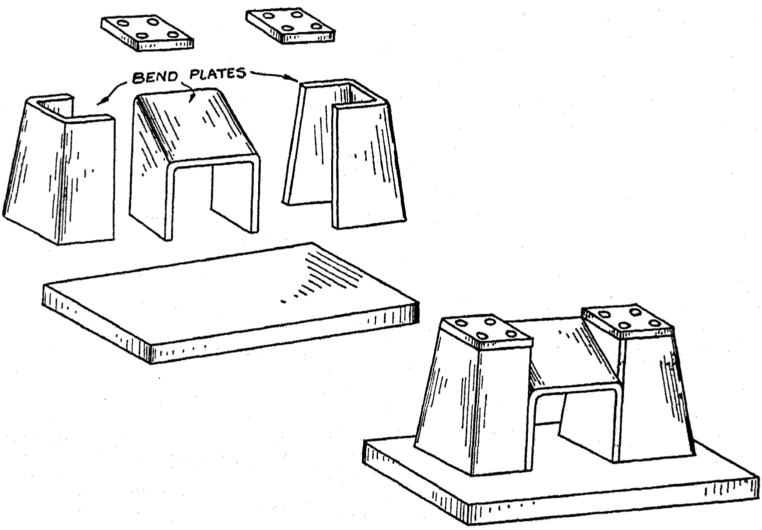


Fig. 688. A support for two bearings. Clearance is provided between the supports for a chain drive. The box-like construction gives extreme stiffness. The parts are readily built by bending as shown.

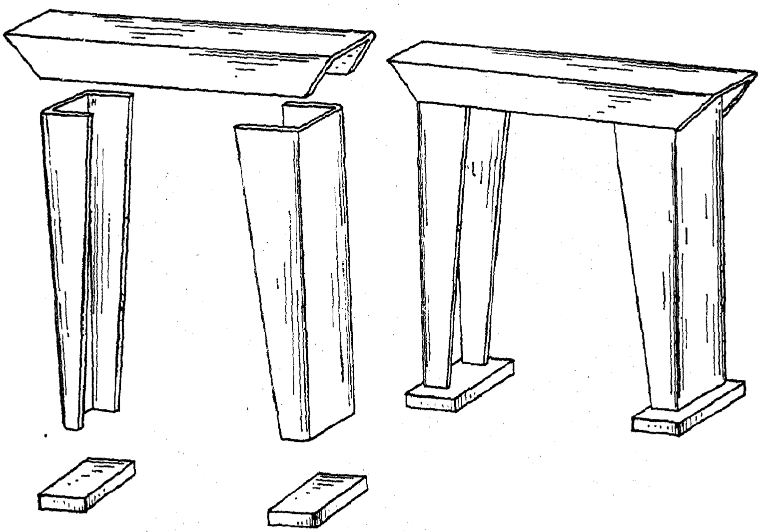


Fig. 689. By using a square shear and bending brake these parts can be prepared for the support shown. Scrap loss is negligible with this strong, light weight construction.

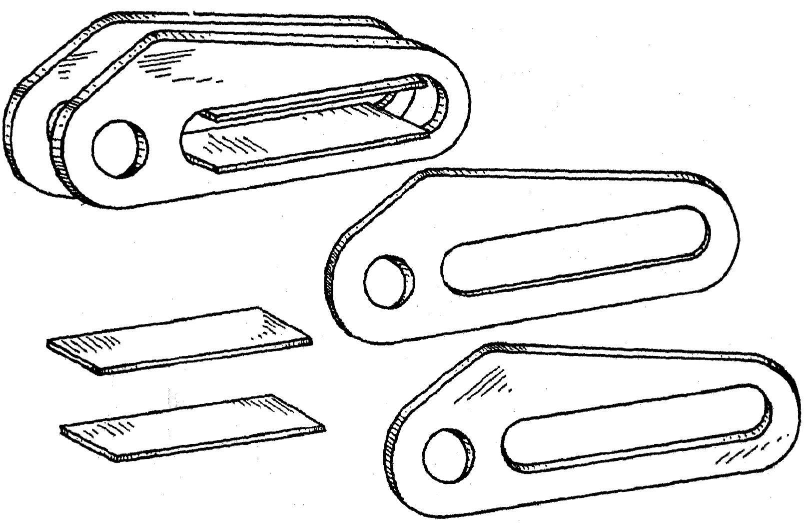


Fig. 690. A combination slide and lever of simple construction. An operating pin between the plates transmits a load to the lever which in turn transmits it to a shaft which is placed through the round holes.

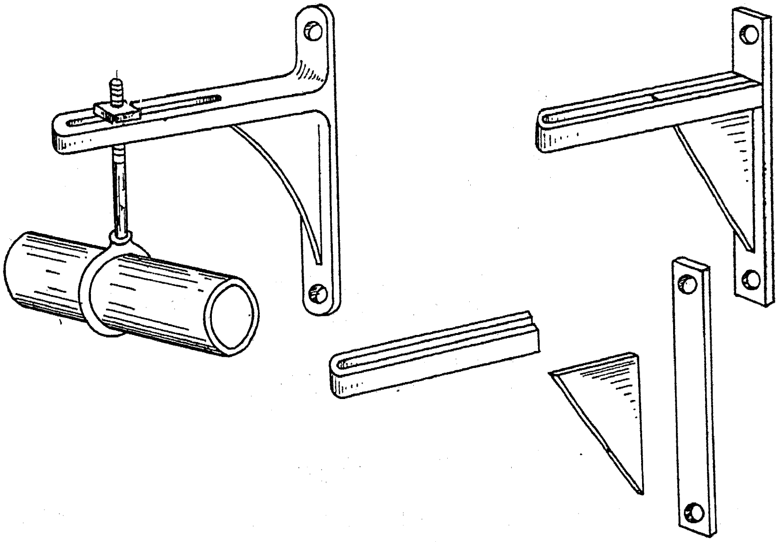


Fig. 691. Pipe hanger supports can be changed over from the cast design shown at the left through the use of plate and bar stock as shown. Note that the plane of the plates and bars is vertical in order to obtain maximum strength and stiffness for the vertical load.

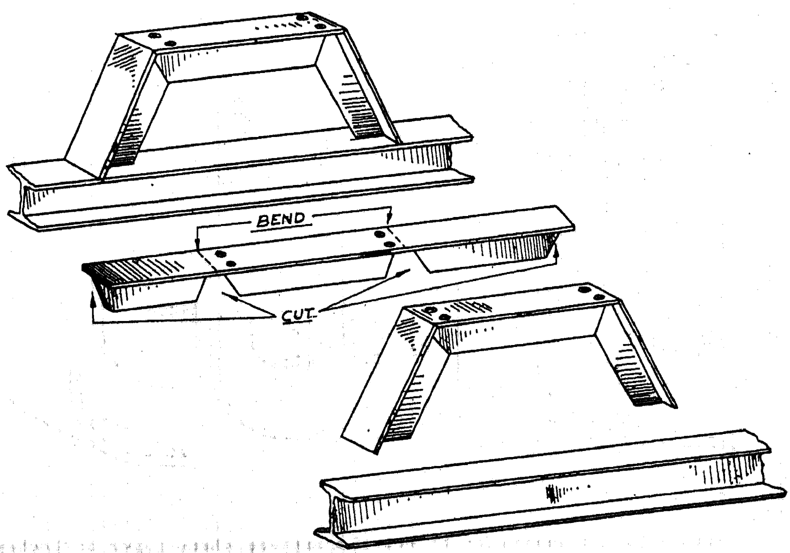


Fig. 692. A simple, inexpensive bearing support for loads which are not extremely severe, made from a T section as shown.

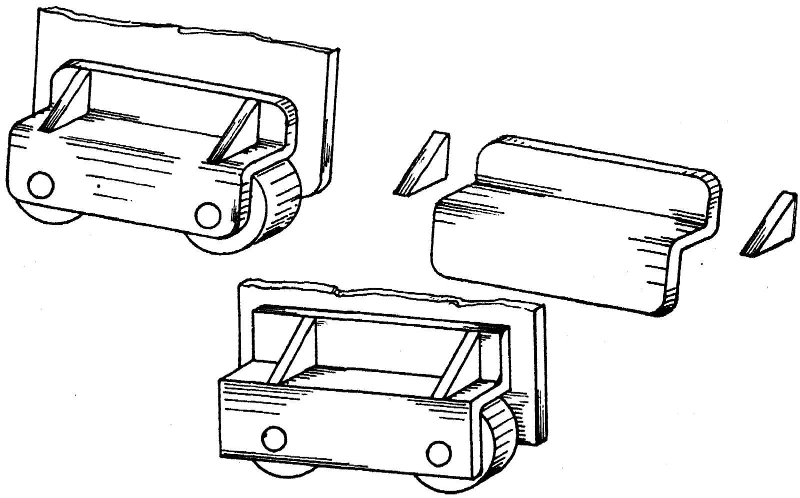


Fig. 693. A support for wheels comprising a Z bar or a plate bent as shown and two triangular braces. The resultant construction is strong, rigid and light weight. Appearance can be improved by arranging the corners as shown in the upper left hand illustration.

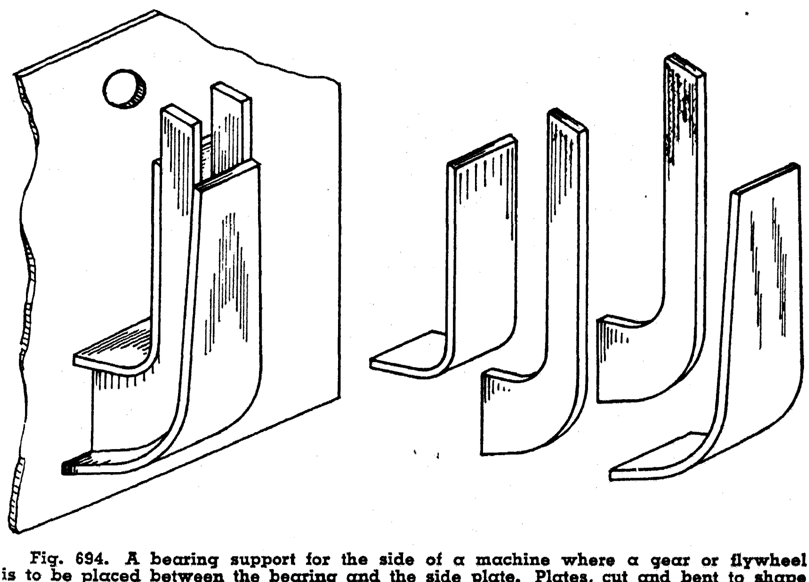


Fig. 694. A bearing support for the side of a machine where a gear or flywheel is to be placed between the bearing and the side plate. Plates, cut and bent to shape and welded provide good rigidity at low cost. Capacity of the design is governed by the size and shape of the component parts.

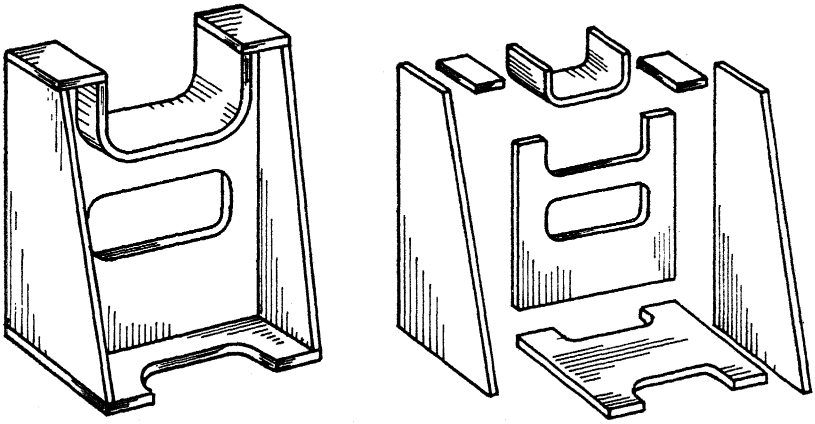


Fig. 695. A bearing support of simple construction comprising flame cut and shear cut plate assuring good appearance, light weight and low cost.

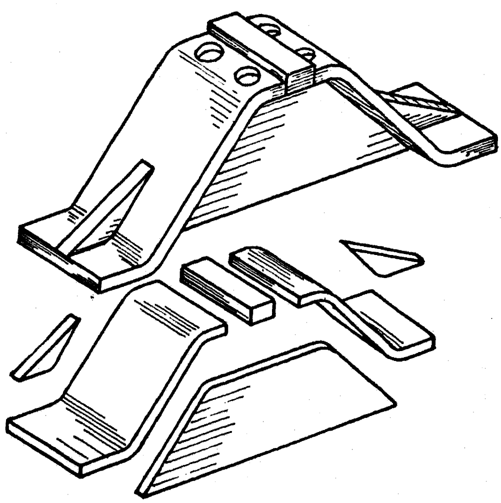


Fig. 696. This support includes an insert in the top surface which can be especially machined. This assembly provides an exceptionally strong, rigid construction.

Complete Assemblies.—As illustrative of the use and application of the various items and subjects previously discussed in reference to welded fabrication, several complete assemblies are shown involving the use of the basic units, and elements.

In designing a base or support for special equipment, the requirements were that it be rigid, of minimum cost and simple to fabricate.

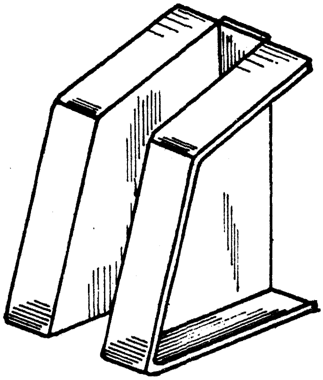
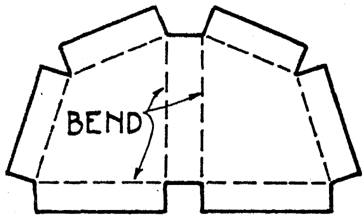



Fig. 697. An interesting support made from plate, cut and bent then welded. Layout of the plate is shown at the right. This plan may be used for a wide variety of similar designs of many shapes and sizes.

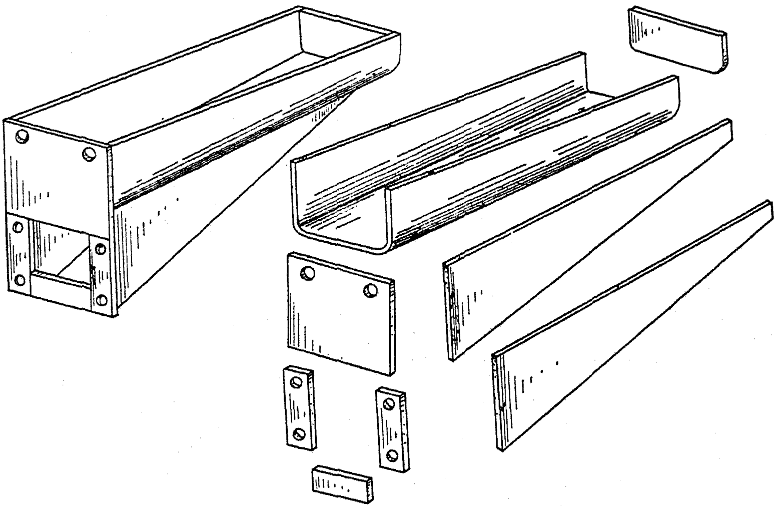


Fig. 698. A chip pan or trough. The space below the pan for auxiliary equipment can be readily varied as to its depth or shape.

Made of rolled steel (Fig. 699), the supporting elements have maximum rigidity, are readily prepared (sheared and bent) and fabricated. The elements are all readily accessible for welding. Note the simplicity of the design—a bent plate with web plate inserted. The result is a simple, neat-appearing, rigid base, (Fig. 700).

Following the same general design, i.e., a web and flange construction, the parts for a press frame (Fig. 701) are made of rolled steel plate, flame-cut and bent to shape. The rib, or web, laid out and cut from mill stock so that minimum of scrap will result. Note

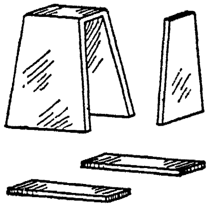


Fig. 699.

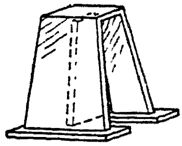


Fig. 700.

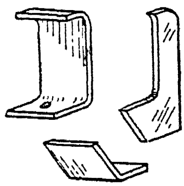


Fig. 701.

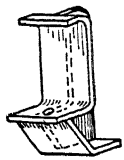


Fig. 702.

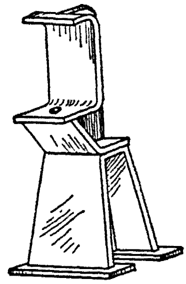


Fig. 703.

the clearance below the bed-plate and the hole in the plate to allow parts to extend through. (Fig. 702.)

The assembly of base and frame (Fig. 703) shows how the web of the base and the web of the press line up—how easily changes in the design may be made to meet special requirements, and how rigid and strong the entire assembly is.

The initial development of another example along the same lines (Fig. 704) all parts made from the same size channel, using plates bent to shape for support, with web plates to give stiffness are assembled as shown in Fig. 705 results in a base with resistance to twisting, exceptional strength, constructed easily and at a low cost.

The next part of this assembly is a frame, the parts of which are shown in Fig. 706 is intended to resist a tension load between the end channels. There is a force tending to push the channels apart. Consequently the side members are made of bars. In order to get certain equipment or accessories in place, channels are used as the end members (Fig. 707).

All parts are square-cut from rolled sections and are effectively placed, resulting in a strong, low-cost frame. Base and the frame, are shown assembled in Fig. 708. Two side bars are welded on the frame, permitting the frame to be moved so the point of application of the load may be at any point along the base.

The complete assembly shows why the base was made so strong—with rather light feet. All of the load is between the frame and base, the legs supporting the weight of the parts.

This press costs little to build because its design is simple, no material is wasted, and it is welded.

What appears to be a direct substitute of steel for cast iron may actually be a good design. Then, too, the design limits may be somewhat fixed or restricted as when the part must fit in with other parts. For example, the load, its intensity and direction as well as the space available may be fixed by conditions entirely apart from the design

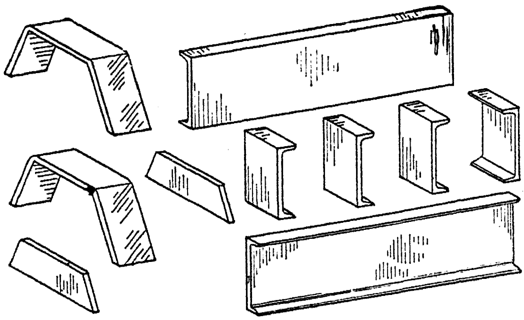


Fig. 704.

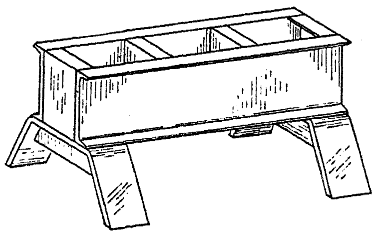


Fig. 705.

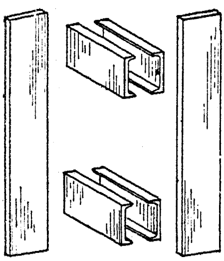


Fig. 706.

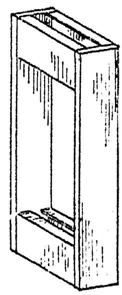


Fig. 707.

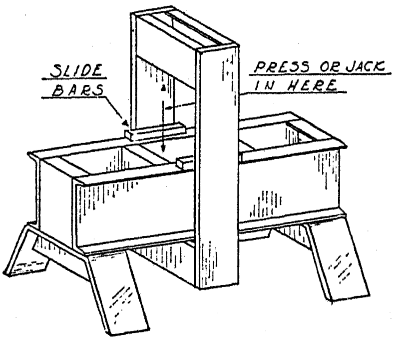


Fig. 708.

of the particular part. Or the space may be limited and the load requirements increased.

Such is the case illustrated in Fig. 709. Here a casting, weighing 500 pounds, must be replaced. The dimensions are fixed. Weight is an important factor and increased service life (nearly double that of the casting), is required.

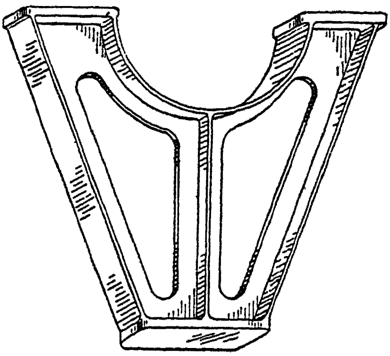


Fig. 709.

Study the casting carefully. Note that it is well designed—conventional, perhaps—but nevertheless, there is not a great deal of excess metal. It is comparatively simple to visualize the part made in welded construction. However, the problem should be given considerable thought in order that the component parts may be as simple as possible and therefore low in cost. The statement that welded construction starts from rolled plates must be kept in mind. (See Fig. 710.)

The top and the feet are, of course, made of bars cut to required length. These are reasonably heavy because they are points of attachment of other equipment. Structurally the shape is an I, as to

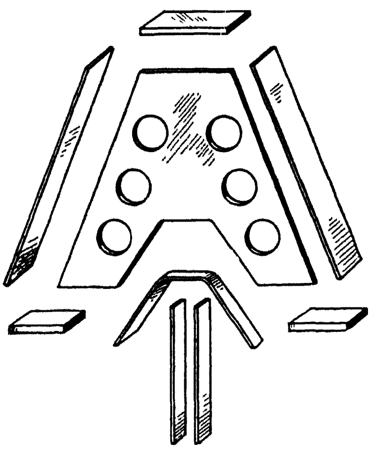


Fig. 710.

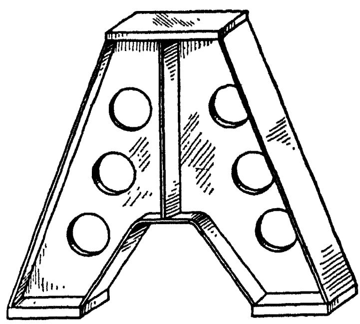


Fig. 711.

cross section, but specially shaped as to depth. This suggests a web plate between two flanges. This major web plate is cut to shape, holes being cut into it to reduce the weight. The flanges are of straight, square-cut plates or bars. Because certain clearances have to be maintained the web is cut away and the flange is carried along

this cut by means of a bent plate. This completes the major part of the design. To stiffen the whole assembly, and to carry the load from upper plate into the base plates, two stiffeners are placed from center of upper plate to lower flange.

The simple square-cut parts—nine of them (Fig. 710)—one bent to form the lower flange, result (Fig. 711) in a welded structure which has twice the load capacity of the casting, no increase in weight. Cost welded is less than casting. In cost of load capacity and service life, a really remarkable result is attained.

When special or experimental machines are required, the limits are usually dimensions and increased load. Generally, only one part is needed. Pattern cost is an item of considerable importance.

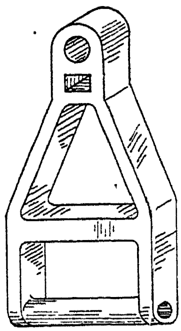


Fig. 712.

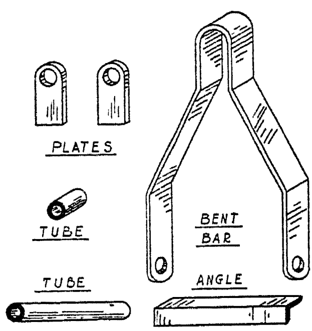


Fig. 713.

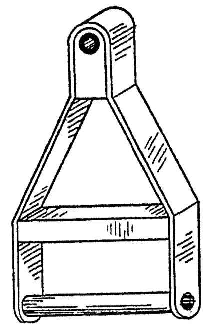


Fig. 714.

The general shape of casting for a special bracket for an experimental machine with requirements of two bearings at right angles to and some distance from each other and an attachment for some special operating devices between the bearings is shown in Fig. 712. A bearing at the top suggests a tube, connected to the longer bearing at the bottom by a strap. The lower bearing, a tube, may be the same size as upper.

The tubes furnish considerable stiffness, the upper being attached to the bent bar by means of two small plates. To increase the stiffness and provide a support for the operating devices, an angle is used, connecting the two sides. Note Fig. 714, first of all the very low scrap, the low cost of forming the component parts and the relative ease of assembly resulting in very stiff, light construction at low cost.

Both examples show the freedom of welded design, even when restricted by space or load conditions. Welded construction starts from rolled shapes.

In the application and use of welding, as applied to the fabrication or manufacture of parts or machines, whether they be machine tools, road machinery or just simple bases, a very complete and intensive study of the relationship existing between several machines of the same kind, as to load requirements and size, will usually result in a very economical application or use of welding.

A fairly large base supporting several machines, or parts of machines with parts not all the same size and varying as to plan and relative positions is shown in Fig. 715. The machine shown is a two-speed skip-hoist which was re-designed for arc welding and is now manufactured of steel arc welded. The hoist consists of several parts, including the winch and brake, supported on one base. The arc welded construction of the sub-bases for motor and brake can

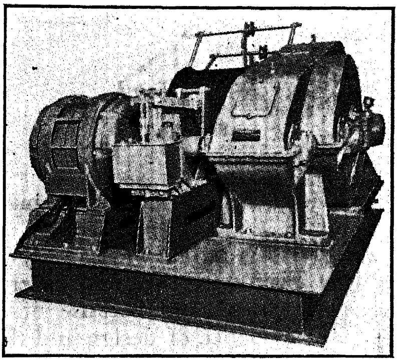


Fig. 715.

readily be seen. The pads for supporting the various parts of the mechanism are made by arc welding flat stock to the cover base of the plate.

In working out the design of a machine in which one base supports several parts, the parts are to be studied as to their shape, plan and elevation. The plans are studied in relation to each other and are arranged as to size. Then they are arranged as to elevation, the elevations being taken from the surface of the main or supporting base.

Then these two, the arrangement of plans and the arrangement of elevations, are compared and it may be found that quite a number of plans of about the same size are at about the same elevation. The resultant classification will probably fall into several general groups.

To summarize, then, the problem is to construct what might be termed "spacers" of several different heights and of different sizes. It is necessary that these be economically constructed, easily and quickly assembled, and easily stocked so quick delivery can be made. A study or illustration of a specific case will illustrate the method and indicate the way to low cost and efficient welded construction. Fig. 716 illustrates the component parts and the assembly of these parts as the "spacer."

Within reasonable limits the top plate may be varied, as to dimensions. The elevation may be taken care of by changes in the supporting plate dimensions.

The design as shown can be changed easily as to dimensions. When it is used on main base to permit alignment of machines of

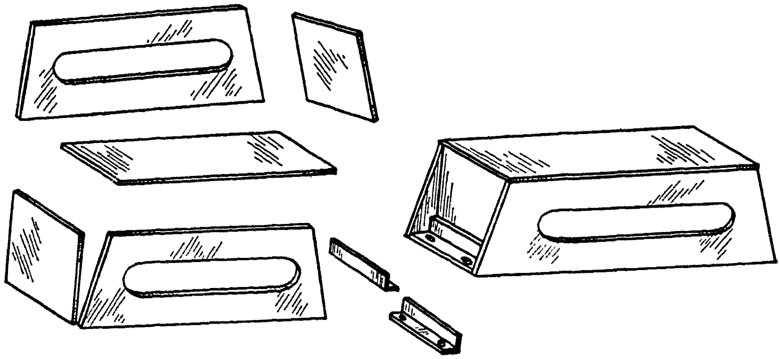


Fig. 716.

different heights, the width, length and height may be readily varied at low cost.

The "spacer" in Fig. 715 is rather wide and low, while the middle one is narrow and high. Even with the great difference in dimensions, their appearance is symmetrical, and because of this symmetry the machine as a whole gives evidence of design and thought.

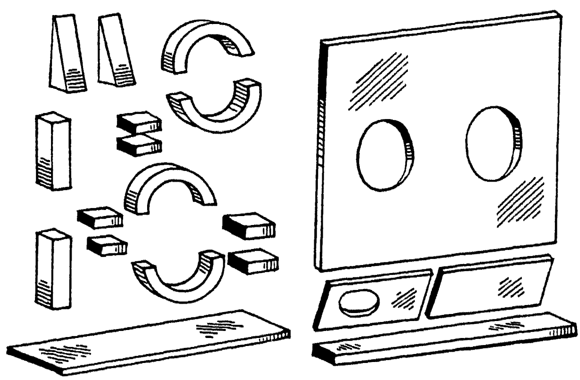


Fig. 717.

The obvious simplicity of the "spacer" design contrasts rather sharply with what appears to be a somewhat complicated gear case shown in Figs. 717 and 718. Fig. 717 shows the component parts and Fig. 718 the parts assembled by welding. A study of this case will show, however, that the component parts are very simple.

All welded design starts from simple elementary parts as plates, bars, etc. A rather casual inspection of Fig. 717 shows the simplicity of the parts. The support plate (not shown) is just a solid plate. The end plates are just rectangular plates as are the top and sides, with holes suitably placed. The rest of the parts are bars, obtained

by cutting bar stock to required sizes. In two cases of the parts shown it is necessary to treat further. In one case the bars are bent (for the bearings); in the other case, the parts are tapered (for the stiffeners).

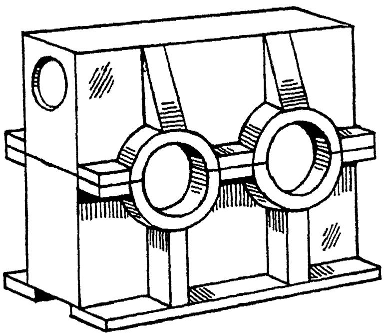


Fig. 718

The assembly of the parts into the final gear case is relatively simple. True, there is quite a number of them, but note that in all cases, the surfaces being attached are flat against each other and at right angles to each other, making for easy assembly, jigging and clamping.

A study of this design and fabrication indicates the ease, the accuracy possible, the low cost, and the service life available with welded construction. The study also suggests, in a brief way, how to attain these highly desirable results.

Conclusion.—These examples of details, sub-assemblies and complete assemblies have shown the relative simplicity of welded design—and how efficiently it can be used to provide improved quality of performance and lower cost. Other examples are shown on Pages 854 to 889.

SUMMARY

In the foregoing discussion of machine design, the advantages of welded fabrication have been pointed out and the procedure for obtaining those benefits has been presented, a step at a time.

Suggestions have been given on how to organize and equip for welded fabrication. Experience has shown that it is advisable to appoint a man of authority to supervise and promote welding developments. Modern production methods and equipment contribute to the success of a welding development program.

A study has been made of the relative properties of the materials used for machine design—cast iron and rolled steel.

It has been pointed out that for greatest simplicity the problem of machine design should be approached on the basis of one part at a time. These parts can be classified into these groups.

1. Bases
2. Covers
3. Containers
4. Wheels
5. Auxiliary parts

A discussion of the various classifications of parts is given.

The problem of design has been analyzed and divided into three methods (1) Direct replacement (2) Conventional (3) Precise; and each of these has been described and illustrated with practical examples.

Following the explanation of how to design, a discussion has been given of the elements (shapes and sections) which are used to produce the desired results.

Finally, actual examples of finished results are given. These welded designs include a wide variety of details, sub-assemblies and complete assemblies taken from actual machines which have been designed for welding. Additional examples are given in the Application Section on Pages 854 to 889 which show case studies of welded design and point out the benefits—improved performance and lower costs—derived by users and manufacturers.

A rule-of-thumb for success in welded design might be stated as follows:

Forget about the former design of conventional construction.

Design to meet functional requirements, using to fullest advantage the new material and the many available shapes and types of steel.

A typical result of this approach is illustrated in Fig. 719.

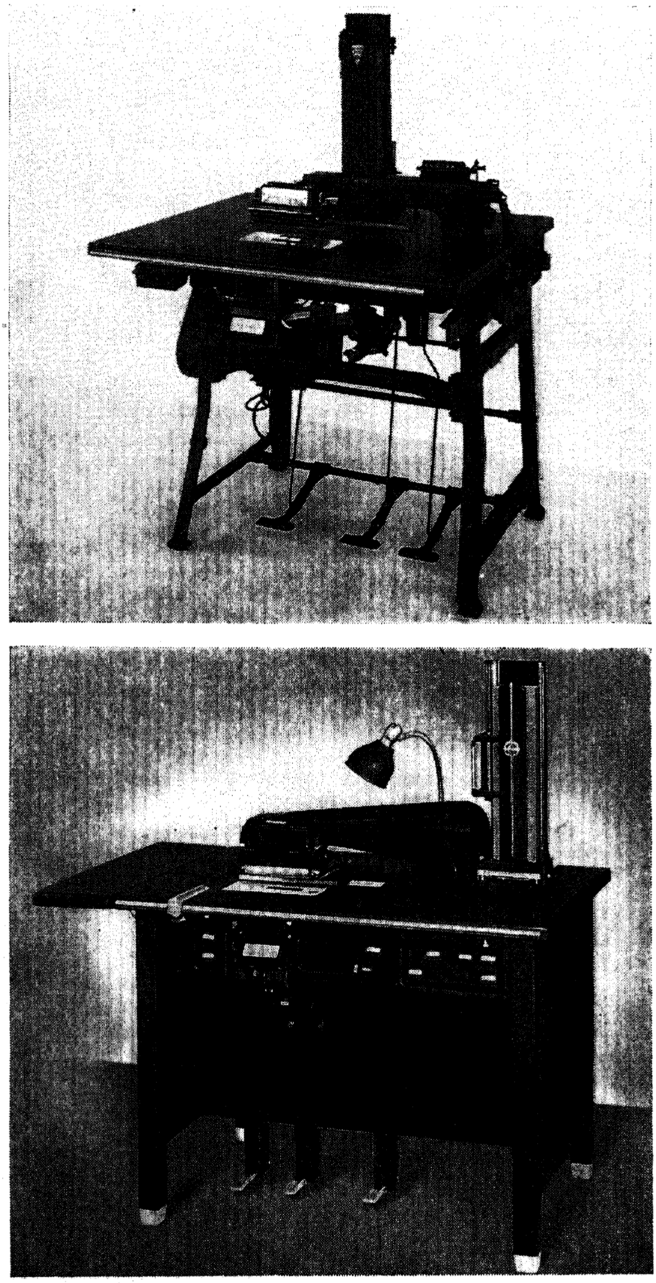


Fig. 719. Result of designing an addressing machine for functional requirements with welded steel. Above: The former design employing cast iron parts extensively. Below: The new welded steel design. Addressing arm of fabricated box section has much less deflection, assuring better results.

PART VII

DESIGNING OF ARC WELDED STRUCTURES

PART VII

DESIGNING OF ARC WELDED STRUCTURES

Design is all-important for it affects the costs of fabrication and erection, at the same time determining the amount of material required. The designer must therefore take full cognizance of the material, time and labor required to reproduce and erect his designs in steel. It is these economic factors which determine the advantages of one type of design over another, assuming that both types of design fulfill the physical requirements.

The ingenuity of steel-fabricators, better equipment, and vastly improved methods and shop practice have produced extraordinary developments within the past two or three years. Where, formerly, only odds and ends were habitually welded, shops now welcome quantity production in structural welded work and handle it very well and expeditiously. They are well equipped to fabricate pressure vessel work under the most rigid inspection requirements, and this personnel and equipment are at the service of owners and engineers who now wish to avail themselves of the benefits and savings incidental to the use of arc-welded steel construction.

Fundamental Advantages of Arc-Welded Design Over Riveted Design.—Extreme simplicity is a fundamental advantage of arc-welded design. This simplicity is attained because arc welding joins two members directly to each other without use of a third or connecting member; whereas to join two members by riveting usually requires an additional member. Fig. 720 explains this graphically. This advantage is respon-

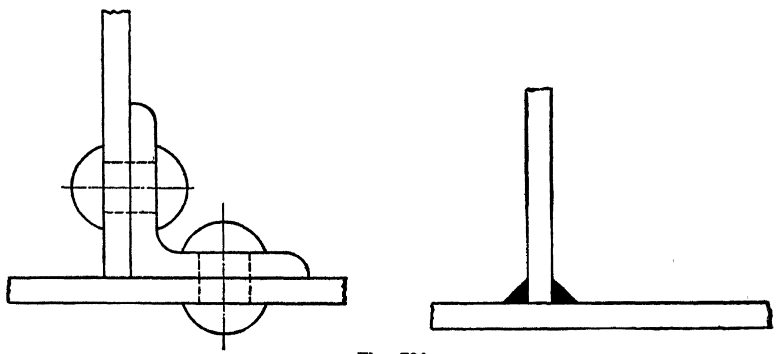


Fig. 720.

sible for a greater or lesser saving in designing and detailing. It should be borne in mind, however, that regardless of the simplicity of arc-welded design the stress at every connection must be accurately calculated and the required amount of weld metal specified.

The chief economy of arc-welded design is due to the fact that it calls for less material, witness the comparative illustrations given previously. For almost all types of connections, the arc-welded design is more eco-

Note: Most drawings used in this chapter are for illustrative purposes only. For simplification, A.W.S. Symbols (see Page 44) are omitted.

nomical in material requirements. Trusses properly designed for arc welding require practically no gusset plates. Because the electric arc fuses one member directly into another, an entire structure so fabricated actually is and acts as a single member. For this reason arc-welded design usually permits the use of lighter members than a riveted design. A saving in steel results for arc-welded design which averages approximately 15% for buildings so designed to date. In the case of arc-welded mill buildings containing a large number of trusses, the saving in steel often amounts to as high as 25%.

The simplicity of arc-welded design means more than the saving of weight and material. In the fabricating process it is apparent in a different form.

The handling of material is a large item in the cost of shop fabrication. Naturally the fewer pieces and the less weight to handle the lower the fabricating costs. With this in mind consider now the comparative examples of arc-welded and riveted design which were cited previously. To make the riveted connection, requires the handling of three pieces. The arc-welded connection calls for the handling of only two pieces. To make the riveted connection holes must be punched in all three members. No punching is required for the arc-welded connection. The punching also involves more laying out. Three separate operations and two different machines are required to make the riveted connection. The arc-welded connection requires only two operations and only a welding machine for equipment.

From the above comparison of a fundamental detail, some of the fabricating economies of arc-welded design are readily apparent.

By use of the proper arc-welded design much of the handling of the main members can be eliminated. Instead of punching main members for temporary bolted field connections small clip angles or plates can be punched, carried to, and arc welded to the main members for such connections. Details of these connections are given later under their proper headings.

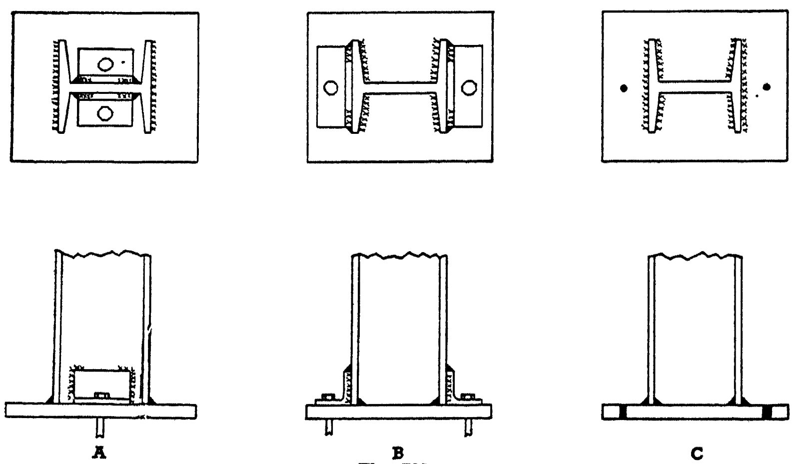


Fig. 721.

Ingenuity in designing simple details such as those described above results in substantial saving in shop fabrication and in erection in the field.

Column Base Plates.—The accompanying illustrations, Fig. 721, show typical details of arc-welded column bases. Note the simplicity of the designs for arc-welded fabrication.

Illustrations *A* and *B* are designed for cases where column and base plate are erected separately. The angles are shop welded to the column and column field welded to base plate after erection. The design, C, is becoming the standard of fabrication for light columns. In such cases the base plate is first punched for anchor bolts, then shop welded to column.

Column Splices and Connections.—The following details of column splices show various types of designs which eliminate punching of the columns. Note that these details require only handling and punching of small pieces of angles or plates which are easily carried to, and welded to the columns in the shop. The details provide for temporary bolted connections in the field prior to making the permanent welded connections.

Fig. 722 shows a splice for light columns. Angle *a* is shop welded to the lower column and angle *b* to the upper column. The outstanding legs of both angles, having been punched and carried to the columns prior to welding the two column sections, are readily secured together by bolts serving as a temporary field connection until the permanent connection is made by arc welding the sections together along the line *c*.

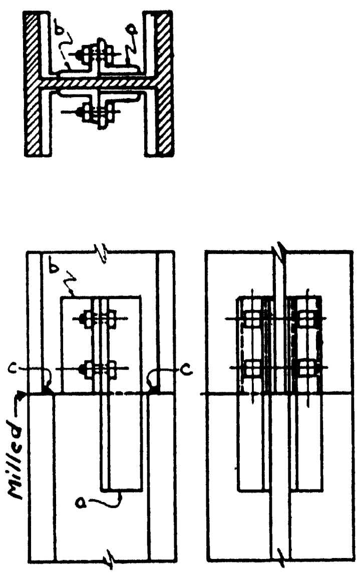


Fig. 722.

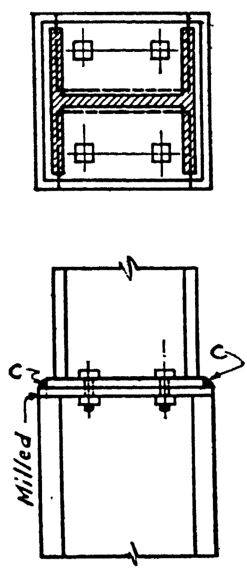
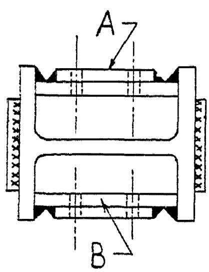


Fig. 723.

A splice for heavy columns is shown in Fig. 723. Two small plates are punched with holes aligned as indicated. They are then carried to the column sections and welded thereto. In the field the column sections are bolted temporarily prior to welding, as indicated at *c*.

Another detail of column splices is illustrated by Fig. 724. It applies particularly to cases where upper and lower column sections are of the same size. Four plates are punched, then welded between the flanges of the two column sections as shown, leaving enough space between the back of the plates and the column web to insert a wrench. Two splice plates are also punched and welded to the lower column section before shipping to the erection site. After bolting in the field as indicated, the permanent connection is made by welding. If flange splices are added, as indicated in the figure, the full bending value of the column is readily developed.



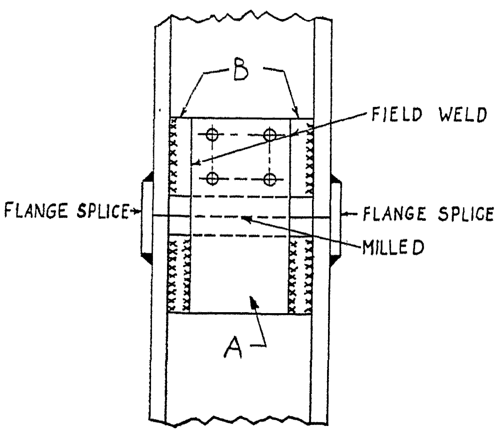


Fig. 724.

Free End Connections—Beams to Column Flanges.—The most direct way of framing a beam to a column is to land the beam on a seat attached to the column and to secure the beam to that seat. Various methods of attaching beams to column seats have been used, such as, tack welding, clamping, hooking and bolting. Tack welding is unsatisfactory because it does not make allowance for plumbing the building. Clamping beams to column seats is not always safe. Hooking, that is, providing a shop welded clip angle on the bottom of the beam, which clip engages a slot in the column seat, is a newly proposed erection method which appears to have merit provided such connections do not require spreading the columns to erect the beams and that due allowance is made for "creeping" in order that successive column tiers may be erected plumb. Bolting has been found, so far, the most satisfactory method of attachment prior to plumbing and final welding.

Bolting a beam to a column seat may be done indirectly or directly. Indirect bolting is shown in Figs. 725 and 726. The purpose of indirect bolting is to avoid punching the beam. This is accomplished by arc welding a connection plate to the bottom flange of the beam. This plate is bolted to the beam seat shop welded to the column, as illustrated herewith by Fig. 725.

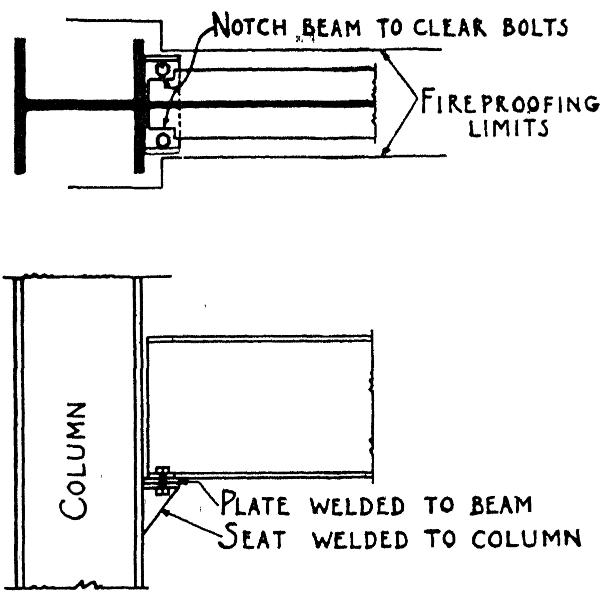


Fig. 725.

The connection shown in Fig. 726 suits beams which are not fireproofed, while the one shown in Fig. 725 is concealed within the usual fireproofing limits and is adaptable to any tier building. The bottom

flange of the beam is notched a little, either with a flame cutter or by means of a coping attachment, to permit setting the bolt close to the beam inside the fireproofing lines.

Direct bolting consists in punching the lower flange of the beam so that the connecting bolts which secure the beam to the column seat pass directly through the beam flange. After the beams have been erected and the frame plumbed, the beams are field welded to the column seat in either case. The method adapted to a particular job depends on the layout of the fabricating shop, the weight of the beams and on the number of holes required. If the beams are heavy, it is often desirable to bring the tool to the material rather than the material to the tool. A portable drill suspended over the welding skids is worthy of consideration.

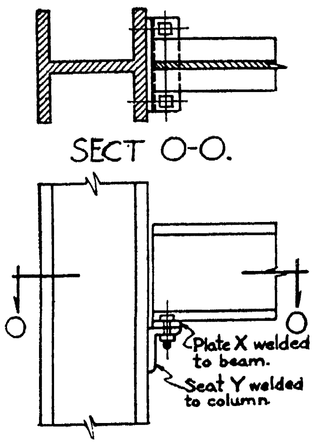


Fig. 726.

The largest shop cost item is handling. That cost is reduced to a minimum when the beams come from the yard or the shears directly to the assembly and welding skids and thence out to paint; while the columns are routed to the assembly and milling, thence to welding and then to painting. A very large number of beams in almost any tier building can be erected with just two holes in the bottom flange at each end, or a punched plate at each end if indirect bolting is used.

Fig. 727 shows four types of column seats. The upper one is a common angle clip. As the beam load has the tendency to bend down the outstanding leg, the heel of the angle should be welded to the column. To do this, a small electrode must be used and the beam's length must be such as not to ride the fillet. Such a seat has a relatively small carrying capacity, but suffices for lightly loaded beams and for column stays. The second seat is the one much favored by fabricators. The sides of the angle are welded to the column and the welds are returned around the top corners of the seat. There is no weld opposite the bottom flange of the beam. The third seat is made from a large tee, or from a suitable beam cut in two longitudinally. This is a strong seat and is adapted to numerous connections. When a beam section is used, it is essential that

the beam selected be one whose flange is square with the web. The fourth type is a large clip angle provided with three stiffeners and four slotted plug-welds and may be used for particularly heavy loads. The slotted plug welds are used where it is impossible to get enough weld metal along edges of angle to withstand load.

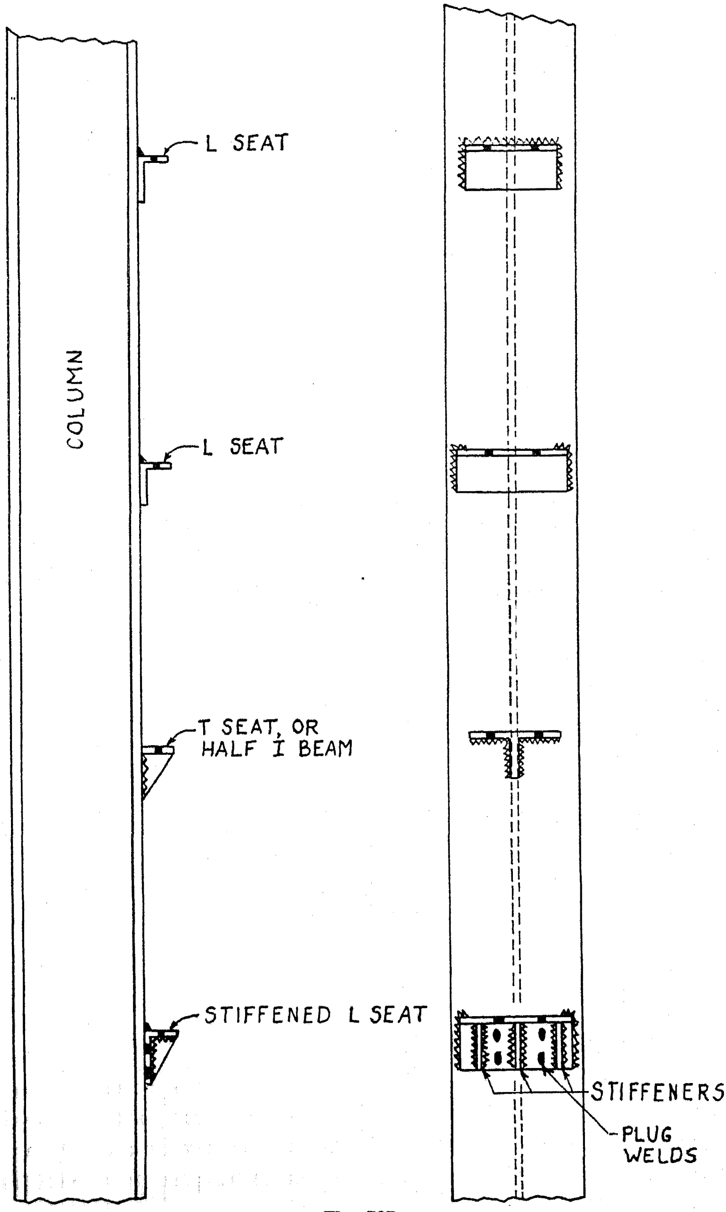


Fig. 727.

The various positions of a beam framing to a column flange are illustrated in Fig. 729. In positions *A* and *B*, all the beam flange is opposite the column flange and the seats shown in Figs. 725 to 728 inclusive, apply directly.

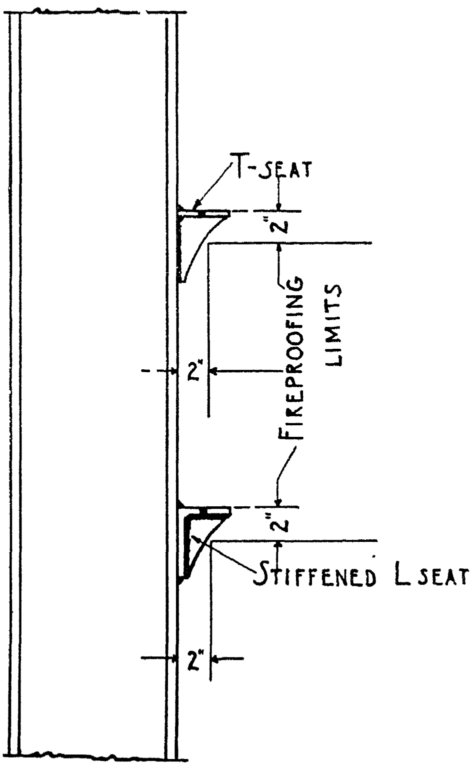


Fig. 728.

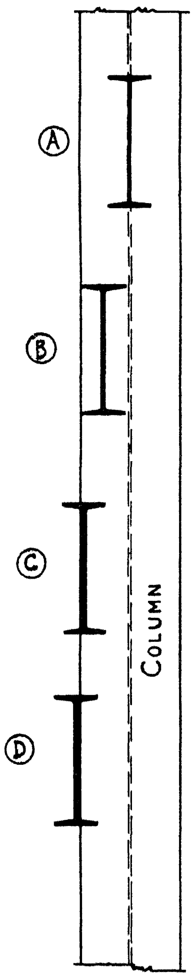


Fig. 729.

In position *C*, the web of the beam comes opposite the edge of the column's flange. For this condition an angle seat, with or without stiffener, Fig. 730, welded on three sides to the face of the column and on the back along the edge of the column, is adapted to a wide range of loads.

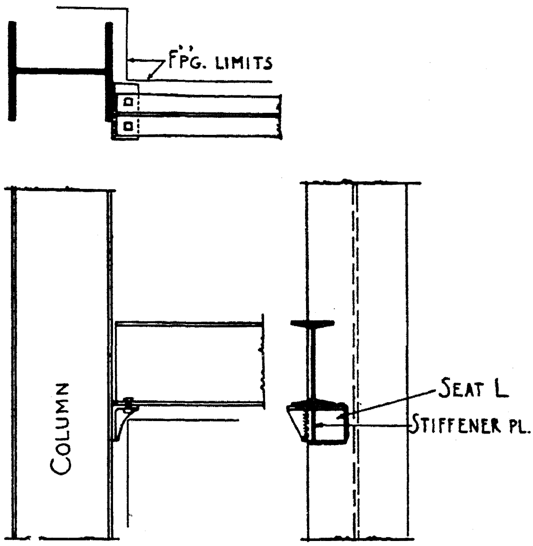


Fig. 730.

In Fig. 731, a seat for the same beam position (C), but with two stiffeners is illustrated. One of the stiffeners is a plate just like the one shown in Fig. 730, the other is an angle, welded to the column so as to resist the twist due to the eccentric position of the angle. The seat proper is a plate welded to the top of the stiffeners and to the column face. This is a stronger seat than the one shown in Fig. 730, but the twist of the angle stiffener should not be overlooked.

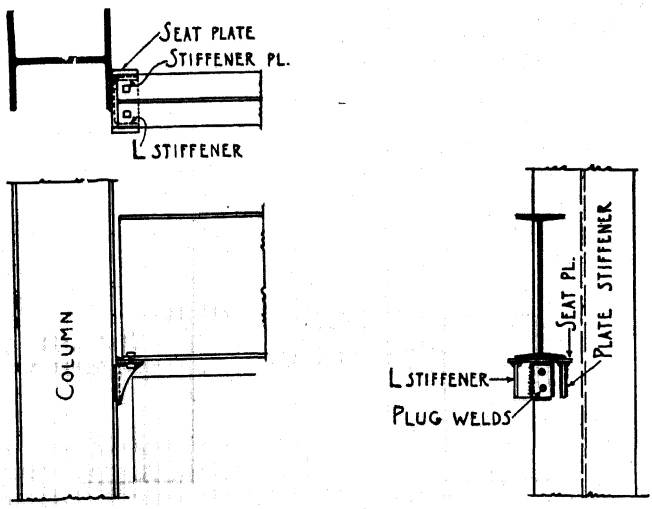


Fig. 731.

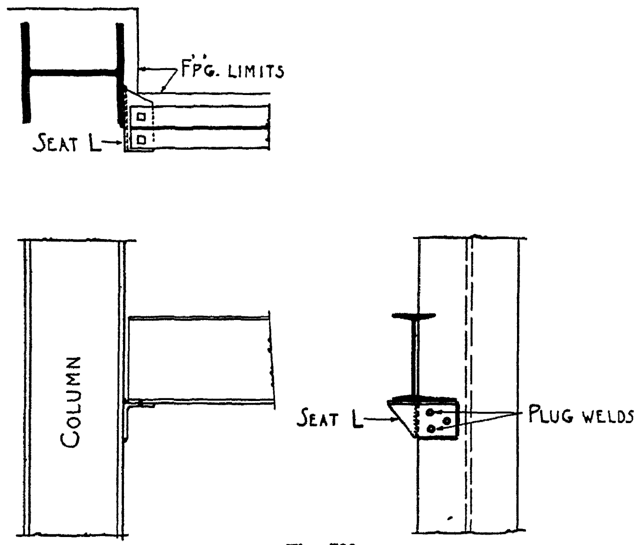


Fig. 732.

In position *D*, Fig. 729, the web of the beam is not intercepted by the column face, but it often happens that a beam in that position may not extend beyond the face of the column. If the beam is a light one, an angle seat of proper thickness may be securely welded to the column flange and allowed to cantilever over far enough beyond the edge to

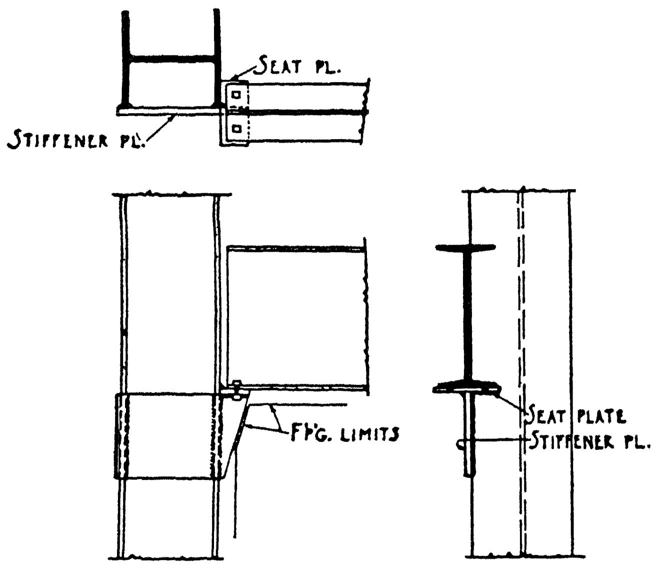
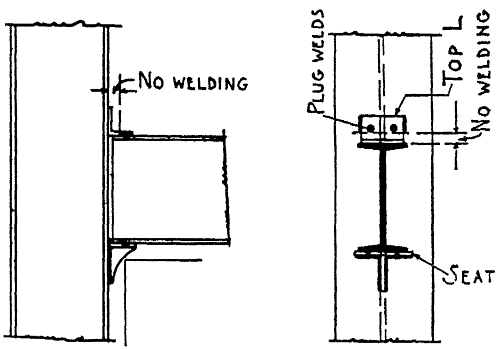


Fig. 733.

furnish a full seat for the beam. This is shown in Fig. 732. If the load is a heavy one, a tee-shaped seat made with two plates, Fig. 733, may be employed; one large plate extends across the column, parallel with the web and is welded to the edge of both flanges while the other plate serves as a seat for the beam.

It will be noted that the lines of fillet weld shown on the inside of the column flanges are hard to make — sometimes impossible; they should be avoided as far as practicable. This can often be done by making the stiffener plate deeper.



Seat & Top L Connection

Fig. 734.

In tier building construction, it is customary to gain as much rigidity as possible at column flange connections by attaching the top of the beam as well as the bottom to the column face. The top of the beam is secured to the column by means of a clip angle. The clip is not intended to fix the end of the beam, that is, the beam, when loaded, is expected to assume the deflection that corresponds to a free-end beam. This deflection causes a rotation of the end of the beam and it is essential that the top clip allow the end of the beam to rotate. The value of the clip as a stiffening element comes into play only after the deflection of the beam has taken place, that is, after the end of the beam has rotated.

In riveted work, the heel of the clip is free to move away from the column face because the rivets holding the clip to the column are placed well above the angle's heel. In welded work, the same flexibility of top angles must be provided. This is readily accomplished, as illustrated in Fig. 734, by keeping all shop and field welding well away from the angle's heel. Fillets along the edges of the vertical legs, Fig. 734, are not very effective against the pull of the beam. The clip should be secured to the column by plug or by slotted welds made through the vertical leg of the angle.

Free End Connections — Beams to Column Webs. — Under this classification are included not only beams framing to the column web itself but also all beams located on the "web side" of the column. The

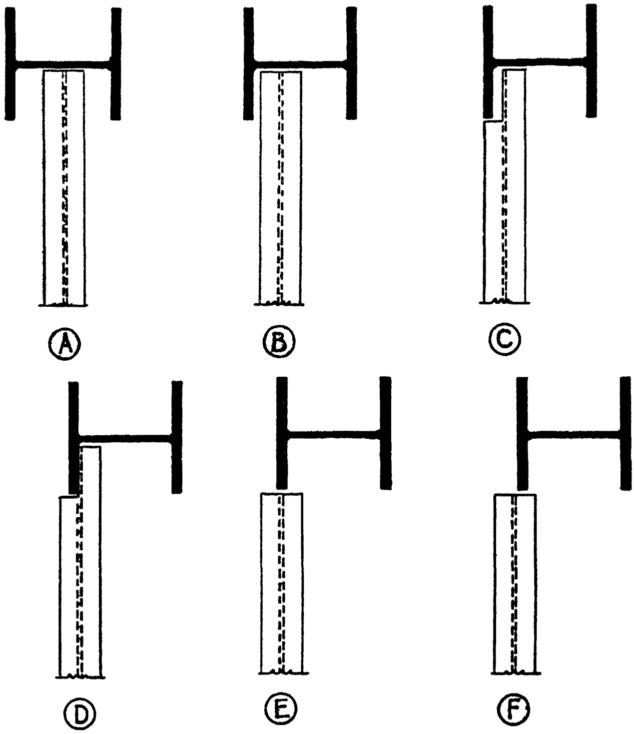


Fig. 735.

various positions of the beam framing to the "web side" of a column are illustrated in Fig. 735. In positions *A* and *B*, the beam entirely clears the column flanges. In position *C* one edge of the beam flange is intercepted by the column flange. Position *D* is similar to *C*; the web of the beam is tight against the column flange. At *E*, the beam web is directly opposite the edge of the column flange. At *F*, the beam web is entirely beyond the column flange.

All seat connections of beams located on the "web side" of columns may be direct or indirect. Fig. 736 shows an indirect seat angle connection for a beam in position *A*. Care should be exercised to locate shop welds so that they will not interfere with erection requirements. In Fig. 736, the shop welds marked *a*, attach the seat plate to the beam; if those fillets were placed along the edge of the beam flanges, they would encroach on the clearance needed for turning the bolts. The angle seat is shop welded to the column at *b*. The seat plate is field welded to the angle seat by means of fillets *c*. For the relation of sizes shown in the figure, if the horizontal leg of the angle seat were welded to the column flanges, there would scarcely be room enough left for fillets *c*—unless the beam were notched, as shown in Fig. 725. The horizontal leg of the seat angle is not shown welded to the column as its function is to furnish a means of attachment for the beam; the load is carried by the vertical

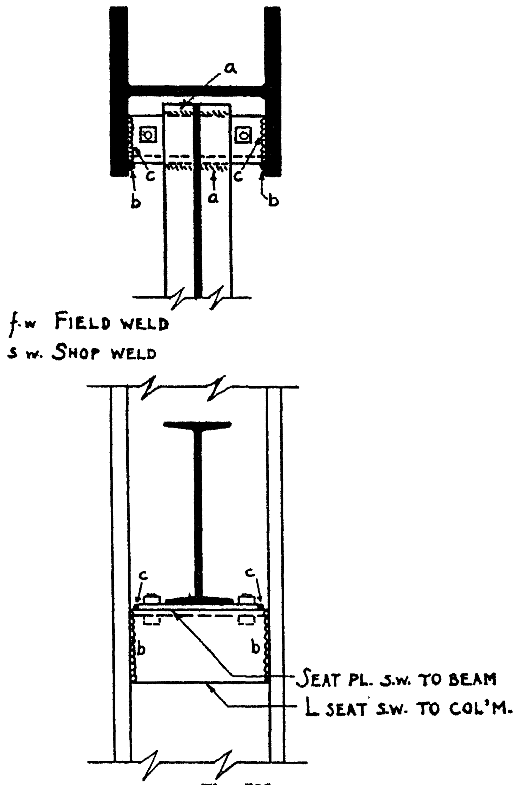


Fig. 736.

leg of the seat angle. By placing the angle seat in the position indicated, that is, in reverse position to that usually adopted, no stiffener is required, the vertical leg of the seat acting as such.

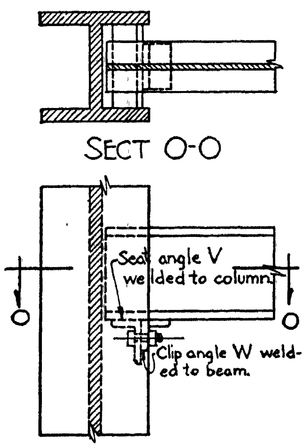


Fig. 737.

A similar connection to that shown in Fig. 736 is illustrated in Fig. 737. The latter connection employs a clip angle instead of a plate shop welded to the bottom of the lower flange of the beam. This connection is bolted through vertical legs of the seat angle and clip angle.

Fig. 738 shows a one-sided indirect connection to an angle seat applicable to beams in positions *B* and *C*, Fig. 735. Because of limited space, the seat plate is placed flush with the flange of the beam on one side and with the end of the beam; consequently the fillets *a* connecting the seat plate to the beam are located at 90 degrees with respect to one another, as shown in Fig. 738. The two erection bolts are located through a wide angle seat, on the same side of the beam. Shop fillets *b* and field welds *c* and *d* connect respectively the angle seat to the column and the seat plate to the angle seat. By increasing the size of the field weld *c*, the flange edge of the beam may be connected to the top of the seat angle.

In Fig. 739, the seat consists of a half I-beam welded to the column web. This type of seat will accommodate beams in positions *A* and *B*. The beam is shown bolted directly to the seat. By making the seat wider,

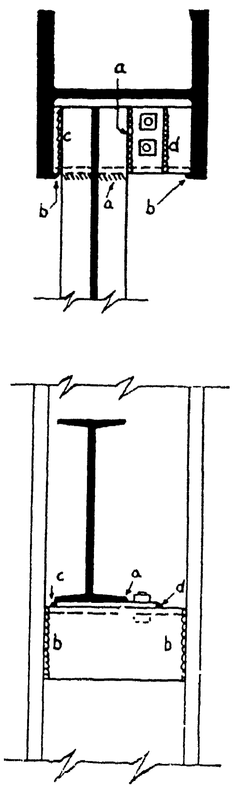


Fig. 738.

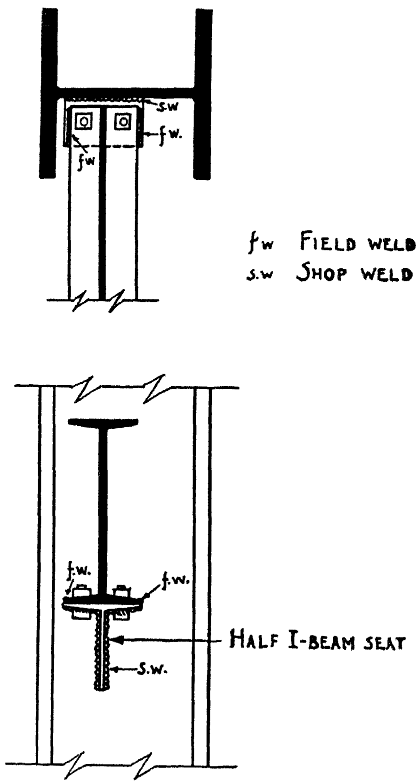


Fig. 739.

the beam may be bolted indirectly through a plate welded to the bottom flange of the beam as in Figs. 736 and 738.

Fig. 740 shows a beam in position C with its web some distance away from the column flange, directly connected to a half I-beam seat welded to the column web. The seat is unsymmetrical so as to bring the web

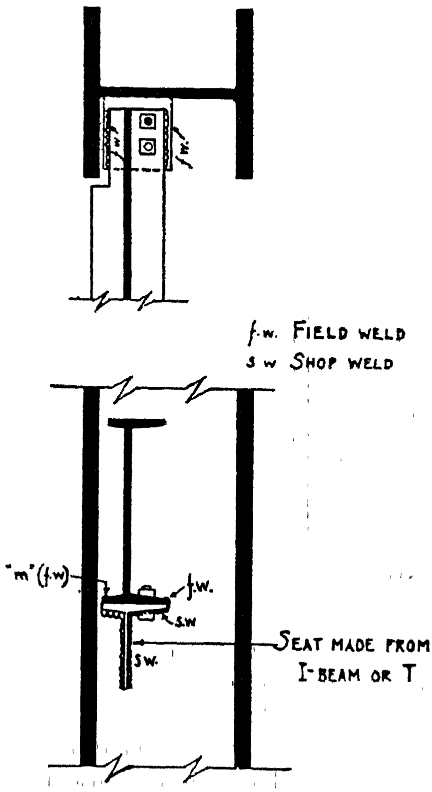


Fig. 740.

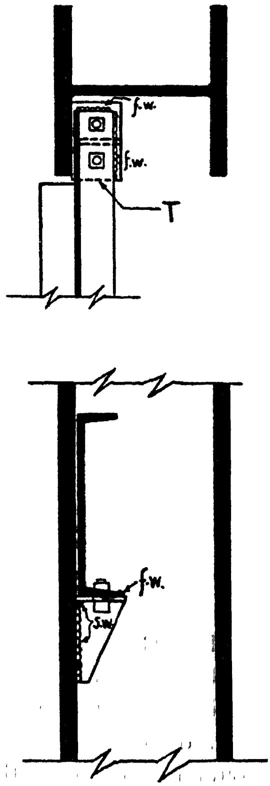


Fig. 741.

of the seat close under the web of the beam and to provide an edge for welding at *m*. This connection can be made indirectly by an arrangement similar to that shown in Fig. 738. To balance the strength of the connection between the seat and the column, the size of the fillet should be increased opposite the shorter segment of the seat's flange.

For beams in position *D*, or in position C when the beam web is quite close to the column flange, a good connection can be provided by welding a half I-beam to the inside of the column flange, as shown in Fig. 741.

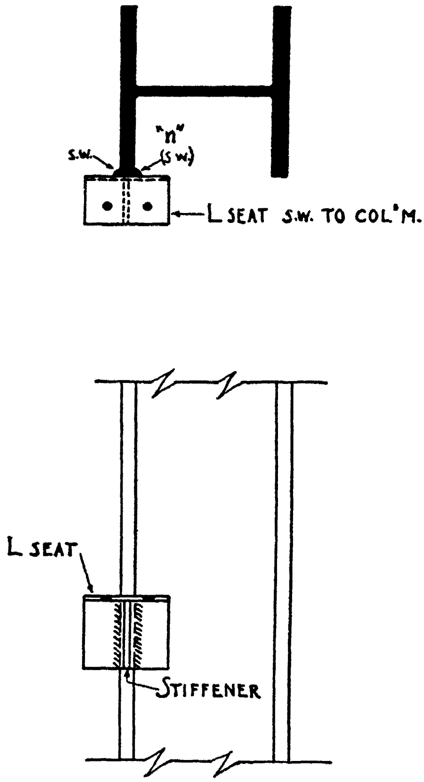


Fig. 742.

Fig. 742 shows a stiffened angle seat for a beam in position *E*. The angle is welded to each side of the flange. This is a bad detail: the seat angle cannot very well be clamped to the column; the weld marked *n* is hard to reach; the two welds cannot be made without turning the column over; finally, the seat is easy to knock off during transportation and handling. Such details should be avoided.

However, a detail should not be condemned just because it requires turning the column over, as connections are generally required on several faces of the same column. But special care is then necessary to insure that the welding be completed before the column has been turned to the next position.

A good connection for beams in position *E* is shown in Fig. 743. It is made of two plates suitably shaped to remain entirely within the fireproofing lines. The seat plate is notched and welded to both sides of the column flange; the stiffener is welded to the edge of the column flange.

Both plates are completely welded without turning the column. Such a connection can be used to resist a considerable bending moment. The projection beyond the face of the column will seldom interfere with the connection of a beam framing simultaneously at about the same level to the adjacent column flange.

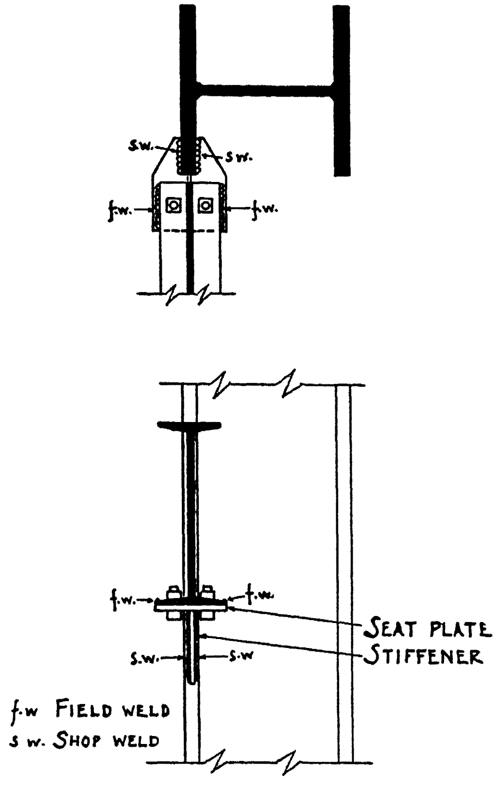


Fig. 743.

Another strong connection for a beam in position *E* is shown in Fig. 744. It consists of an angle welded to both flange edges of the column and provided with a stiffener plate under the beam. The outstanding leg of the seat angle is flame-cut as shown, to clear the fireproofing lines. This seat is not in the way of beams framing to the column flange.

Fig. 745 shows the same connection arranged to seat a beam in position *F*. It is evident that this type of connection is suitable for beams placed in any of the positions shown in Fig. 735.

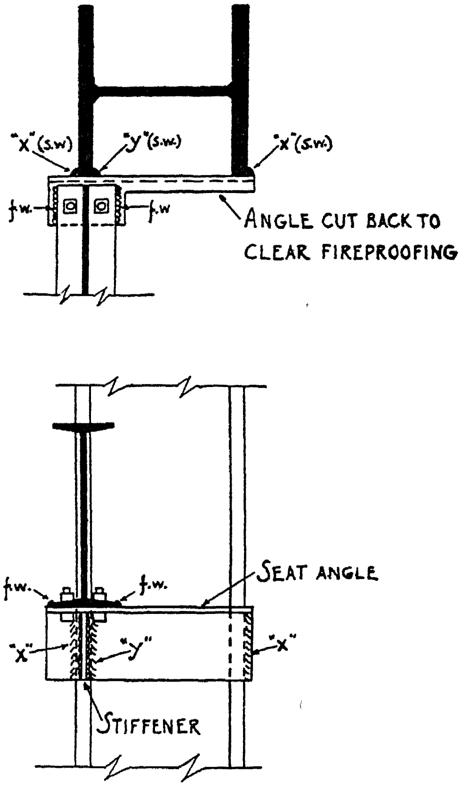


Fig. 744.

In Figs. 744 and 745, the seat is placed under the column shaft, clamped in place and the fillets marked *x* made at once. If a fillet *y* is required, it is made after the column has been turned.

When there is no interference from beams framing to the column flanges, a seat such as that shown in Fig. 746 is most satisfactory for beams located in position *F*. This is really a flange connection carrying a beam parallel to the column flange instead of perpendicular to it.

Most free end connections of beams to columns can be made by means of seats. They are advantageous in that they reduce the field-welding to a minimum.

Care should be taken to set all seats square and level so that erection bolts will fit the holes freely.

All seat angles, plates, tees and other fittings should be cut true and be clamped tight so as to exclude air gaps and so as to avoid the necessity of building up welds.

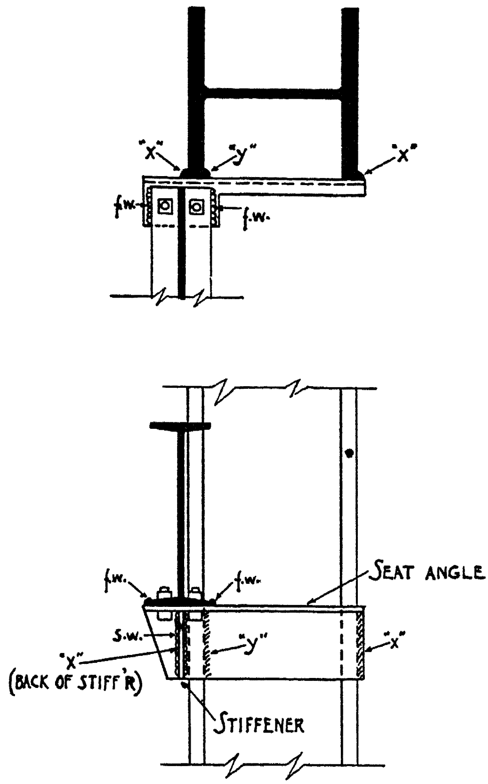


Fig. 745.

Welding skids and jigs should always be so located as to avoid interference with placing the connections, seats, etc., and clamping them to the column shaft.

Though the connections shown herewith are designed primarily for field bolting prior to welding there may be some cases where members may be temporarily secured by clamps or other methods which would not necessitate punching of members or of details.

Rigid End Connections—Beams to Columns.—Rigid end connections are used either to obtain continuous beam action or else to obtain stiffness. These two distinct cases are welded by methods appropriate to each case. In welding beams rigidly to columns, attention must be paid to the stresses induced by such connections and suitable provisions made.

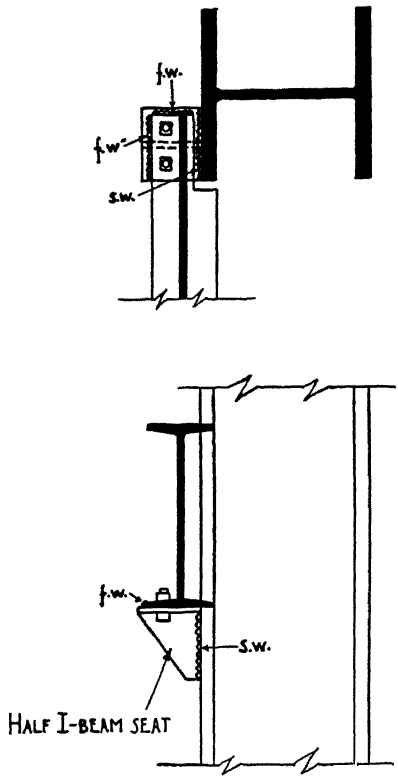


Fig. 746.

Fig. 747 shows a beam loaded by four vertical loads acting downward. The loads shown are the only loads acting on the beam.

Fig. 748 shows a beam carrying a distributed load W acting downward; load W is the only load acting on the beam.

If those beams are connected to their supporting columns only by means of a seat, they will rock on that seat and bend as shown in Fig. 749; the ends of the beam, parallel to the columns in Figs. 747 and 748, now forming an angle a with the columns.

If those beams are connected to the columns by a seat and top angle connection, as illustrated in Fig. 734, the bending will again be that shown in Fig. 749 and the top angle will distort as pictured in Fig. 750.

If beams carrying vertical loads, as those shown in Figs. 747 and 748, are now supported by heavy column sections and securely connected to them at points marked x and y, Fig. 751, the bending of the beams as

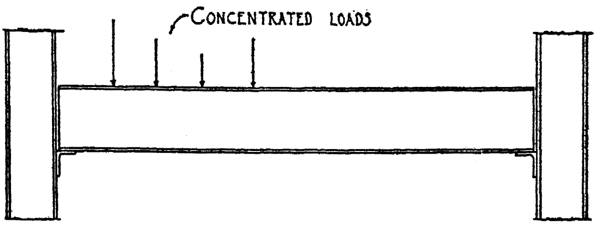


Fig. 747.

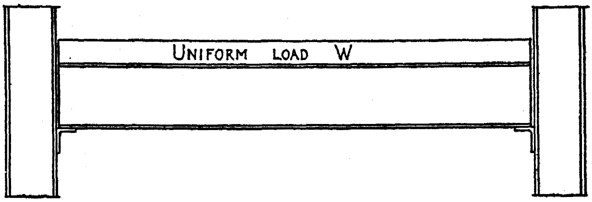


Fig. 748.

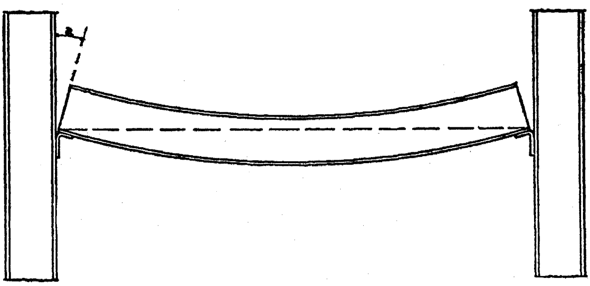


Fig. 749.

pictured in Fig. 749 will be decreased very materially due to the help obtained by forcing the ends of the beam to bend too. This end bending is obtained by making the beam, Fig. 751, pull on the column at x and push against the column at the seat y. Suppose for a moment that the

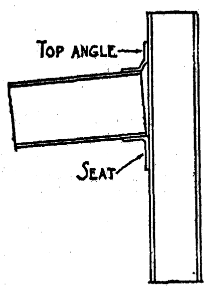


Fig. 750.

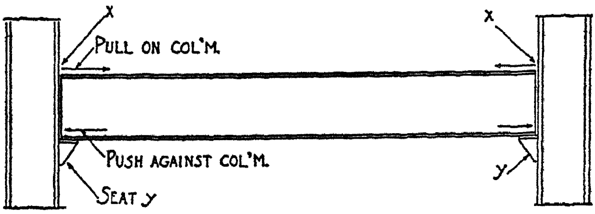


Fig. 751.

heavy supporting columns are made of some absolutely inelastic material which is totally undistorted by the pull of the beam at x and by the push at y: since the beam was level when erected, since it was level when securely connected to the column at x and at y, the beam bending due to the vertical loads, Figs. 747 and 748, will be as pictured in Fig. 752, the ends of the beam being still vertical and parallel to the face of the assumed undistorted columns.

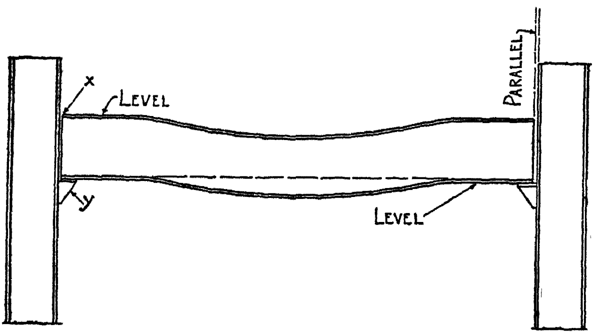


Fig. 752.

The columns, however, are not made of inelastic material and consequently the pull at x and the push at y, Fig. 751, does distort them as shown in Fig. 753. The ends of the beam are now not quite level; the columns are slightly distorted. The ends of the beam are now parallel

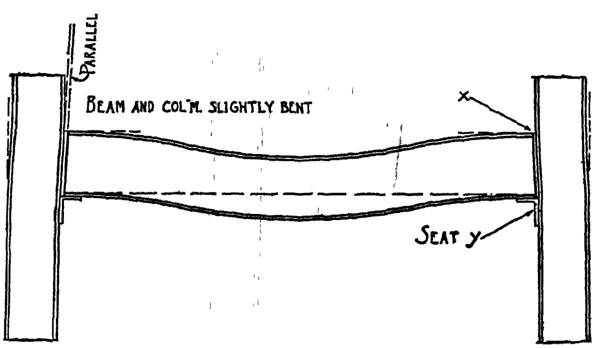


Fig. 753.

to that portion of the columns located between x and y. The stresses at the middle of the beam are a little greater and those at the ends, a little less than they were before the beam had had time to distort the columns as represented in Fig. 753. But in designing stiff end connections, the conditions represented in Fig. 752 are the ones to be provided for.

When rigid end connections are designed for downward vertical loads only, they are designed to obtain continuous beam action; there can never be anything but a pull (tension) at x nor can there ever be anything but a push (compression) at the seat y.

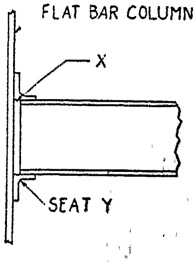


Fig. 754.

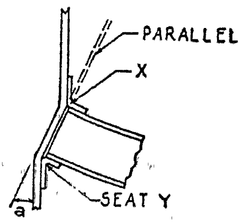


Fig. 755.

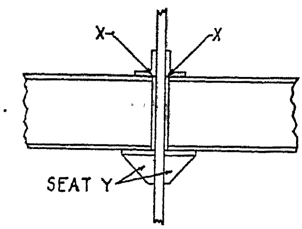


Fig. 756.

It was assumed, Fig. 750, that the columns supporting the beam were heavy sections. If, instead, they were very light sections — to make the point clear suppose that they were actually flat bars, Fig. 754, just strong enough to stand up straight under a direct vertical load — it is evident that the pull at x and the push at y will distort the bar column until the beam bends as much as was pictured in Fig. 749. The ends of the beam, Fig. 755, will be parallel to the column section comprised between the top and bottom flanges of the beam, but that section of the column will be distorted until it makes the same angle a with the sections of the column above and below the beam as the end of the beam made with the face of the column in Fig. 749. The beam will bend just as much as in Fig. 749 because there is no help from connections at x and y, the column being too light to offer any resistance.

If, however, the bar column be strong enough to stand up straight under direct vertical loads, and if, as in Fig. 754, the loads and bending moments are equal on the opposite faces of this column, the beams being securely attached at x and y, the pull at x and the push at y will balance each other. With approximately equal spans and distributed loading, these are the conditions usually assumed in ordinary building design.

In the uppermost stories, the size of columns required for vertical loads is usually small. If rigid end connections are to be used, it is well to bear in mind that, while distributed loads are normally assumed for design purposes, unbalanced loads tending to produce the conditions pictured in Fig. 755 may arise — consequently the upper columns should be designed to resist a reasonable amount of bending.

When fixed end connections are used only to obtain continuous beam action, the stress at x, Fig. 757, is always tension and that at y is always compression. In designing connections for continuous beam action, those stresses must then be provided for.

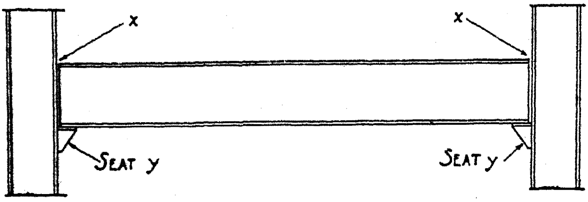


Fig. 757.

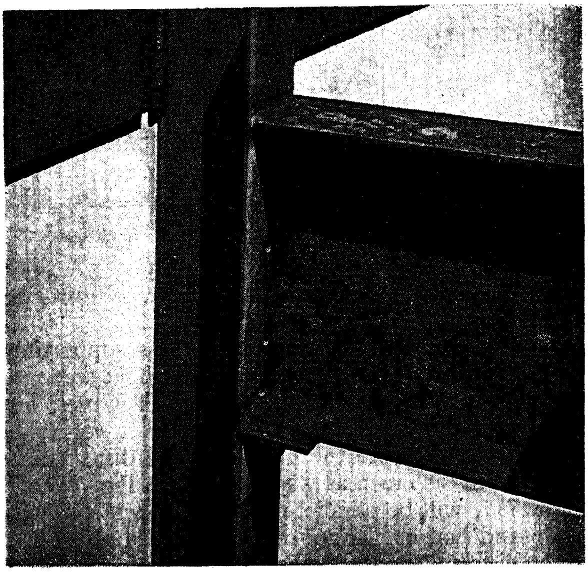


Fig. 758.

The simplest fixed connection of a beam to a column consists in setting the beam on a seat, shop-welded to the column, Fig. 758, and welding the beam directly to the column. This method can be used when the bending moment required of the fixed connection does not exceed the capacity of the fillets connecting the beam flanges to the column. When the moment required does exceed that capacity, some other style of connection is required.

Welds and Calculations for Continuous Beam Action.—There are three different kinds of welds used in attaching beams to columns. The most common is the *fillet* weld, shown in Fig. 759. This weld is never in the direct line of action of the stress. In Fig. 759, the pull on the horizontal plate is represented by *F;* the resistance of the fillet weld is at *R*, the two opposing forces being a distance *e* out of line. This distance *e* is equal to half the thickness of the plate plus one third the height of the fillet. Whenever it is practicable, especially in important connections, fillet welds should be made in pairs, Fig. 760, so that the opposing forces may balance squarely.

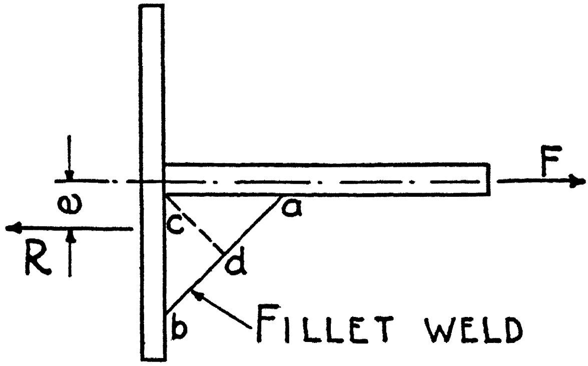


Fig. 759.

In the following calculations of strength of welds the unit stresses employed for fillet welds are those tabulated on Page 66 for welds. For V welds and for butt welds, the unit stresses used are as follows:

Shear: 14,300 lbs. per sq. in.
Tension: 16,250 lbs. per sq. in.
Compression: 18,750 lbs. per sq. in.

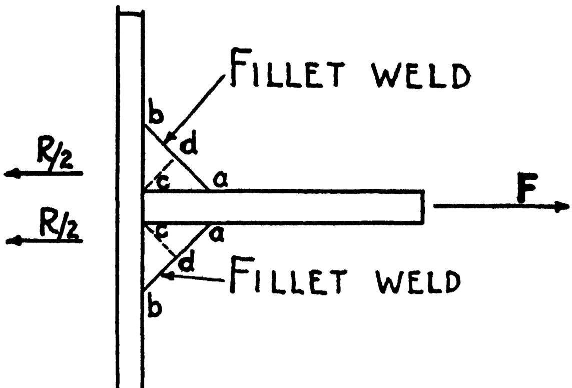


Fig. 760.

In calculating the strength of fillet welds, made by the shielded arc process, the stress is computed through the throat of the fillet. The throat of the weld shown in Fig. 759 is the line *cd*, the length of which, for ordinary 45 degree fillets, is always .7 of the size of the fillet, *ac* or *bc*. If a $3/8''$ fillet is specified, $ac = bc = 3/8''$; if a $1/4''$ fillet is called for, $ac = bc = 1/4''$. In the first case, the strength of the fillet weld is $.7 \times 3/8 \times 14300 = 3750$ lbs. per linear inch; in the second case, the strength of the $1/4''$ fillet is $.7 \times 1/4 \times 14300 = 2500$ lbs. per inch of fillet. These are the values given on Page 66.

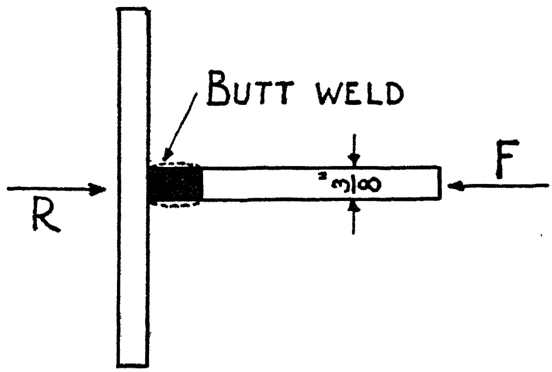


Fig. 761.

The second kind of weld is the *butt* weld, shown in Fig. 761. This weld has the same theoretical section as the plate or member that it connects, though, actually, it is often "reinforced," that is, made to bulge a little, as indicated by the dotted lines. The strength of a butt weld is the cross section of the plate or member connected, in square inches, multiplied by 16250 for tension, by 14300 for shear and by 18750 for compression. In. Fig. 761, the horizontal plate is $\frac{3}{8}''$ thick; the strength of the butt weld then is $\frac{3}{8} \times 16250 = 6100$ lbs. per linear inch in tension; $\frac{3}{8} \times 14300 = 5350$ lbs. per linear inch in shear and $\frac{3}{8} \times 18750 = 7000$ lbs. per linear inch in compression.

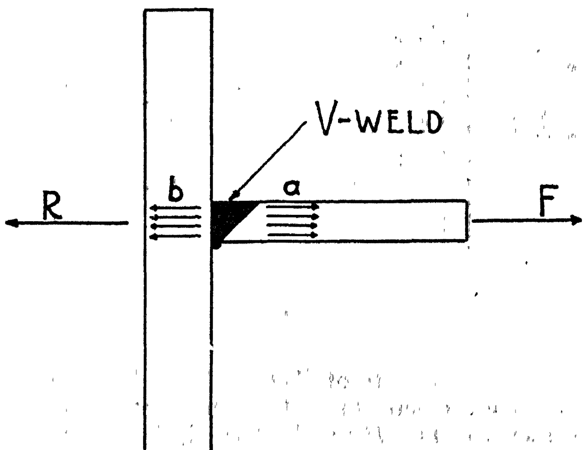


Fig. 762.

The third kind of weld is the "V-weld," shown in Fig. 762. The force F can be considered as resolved into a number of component forces a acting through the "V-weld," resisted by an equal number of forces b

forming the resisting force *R*, which must, of course, be equal to *F*. It is evident that the strength of the "V-weld," just like that of the butt weld, is equal to the cross section of the plate or member connected, in square inches, multiplied by 16250 for tension, by 14300 for shear and by 18750 for compression. In Fig. 762, if the thickness of the horizontal plate is 3/8", the strength of the "V-weld," in tension is $3/8 \times 16250 =$ 6100 lbs. per linear inch; if the plate is 1/2" thick, the "V-weld's" strength is $1/2 \times 16250 = 8125$ lbs. per linear inch.

Fig. 763 shows a 24" 74-lb. beam intended for continuous action. It is supported on seats shop-welded to the columns and its flanges are welded to the columns at points *A, B, C, D*.

The amount of continuous action that can be developed depends on just how strong the connections of the beam flanges to the columns are made.

Considering first the flange connection at *A*, with the beam butting directly against the column flange, suppose a single 1/2" fillet were used, as shown in Fig. 764. The fillet's working strength is 5000 lbs. per lineal inch. As the beam flange is 9" wide, the tension that can be resisted by this single 1/2" fillet is $9 \times 5{,}000 = 45{,}000$ lbs. and the moment that can be resisted is that tension, 45,000 lbs., multiplied by the beam's depth, 2 ft., or 90,000 ft. lbs.

If it is desired as is usually the case, to develop the full working strength of the beam, 256,000 ft. lbs., it is evident that this single 1/2" fillet is far from being sufficient.

The connection shown in Fig. 765 has two 1/2" fillets: one made as in Fig. 764, and the other located under the beam flange, in an overhead position. It should be noted, in passing, that overhead welds, properly made, are just as strong as "flat" welds and, therefore, should not be avoided when, to do so, would require designs that cost more than those requiring overhead welding. The strength of the double fillet is evidently twice that of the single fillet, or 180,000 ft. lbs. This value also is much below the working strength of the beam.

Instead of using fillet welds, a butt weld of a V'd joint may be employed, as shown in Fig. 766. The V is formed by flame-cutting the end of the beam flange at 45 degrees, the usual angle used for a weld of this kind. The beam flange being $9'' \times 11/16''$, the tension strength of this joint will be $9 \times 11/16 \times 16{,}250 = 100{,}000$ lbs. and the working moment, 200,000 ft. lbs. This is more than was obtained from the double fillet, Fig. 765, and the cost of this V-weld is less than that of the double fillet.

At the small expense of bevel cutting the flange, the overhead work is eliminated and the amount of electrode required for the double fillet is a little more than that required for the butt weld. Nevertheless, even the butt weld illustrated in Fig. 766, with a unit stress of 16,250 lbs., under the Fusion Code, develops only 78% of the working strength of the beam.

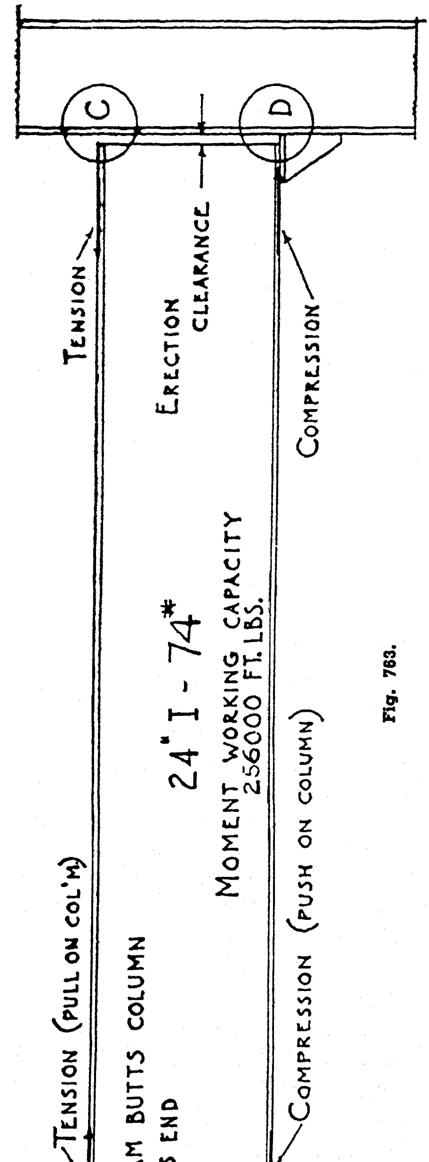


Fig. 763.

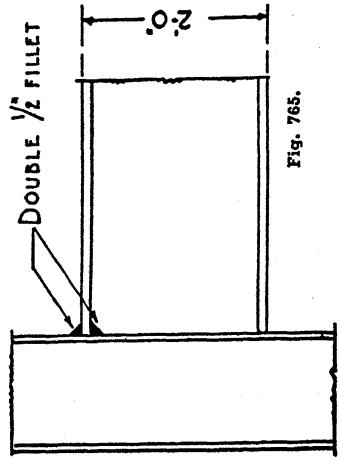


Fig. 765.

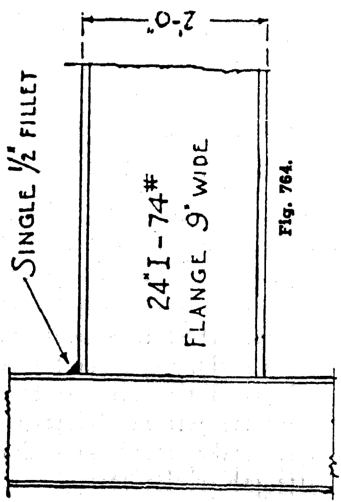


Fig. 764.

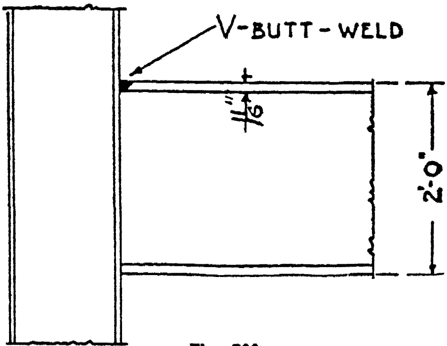


Fig. 766.

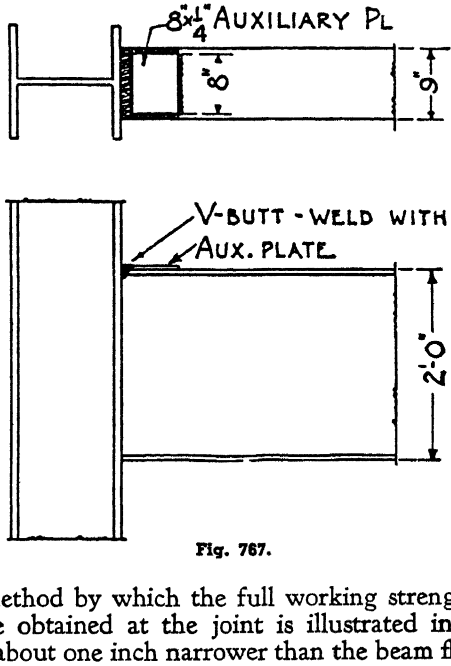


Fig. 767.

A simple method by which the full working strength of the beam may readily be obtained at the joint is illustrated in Fig. 767. An auxiliary plate about one inch narrower than the beam flange is securely welded to it. Both the plate and the beam flange are then bevel cut in one operation. For the case shown in Fig. 767, the tension value of the flange is 100,000 lbs. as above and that of the auxiliary plate is $8 \times \frac{1}{4} \times 16{,}250 = 32{,}500$ lbs. The reinforced flange's tension value is then $100{,}000 + 32{,}500 = 132{,}500$ lbs. and the moment value is $132{,}500 \times 2 = 265{,}000$ ft. lbs., fully developing the beam's working strength.

Attention is called to the fact that butt welds such as the ones shown in Figs. 766 and 767, made by the shielded arc with proper electrodes, constitute precisely the same kind of welding as is used for high pressure piping and for pressure vessels. This is the kind of welding which conforms to the A.S.M.E. Boiler Code.

Considering now the flange connection at *B*, Fig. 763, it is manifest that, since for continuous action, the beam produces only compression against the column, this compression is transferred directly by the beam to the column if the beam is butted against it. A beam cut squarely across with a flame cutter, especially a motor driven cutter, will produce a surface very nearly equal to a milled face and well suited for the purpose intended.

Since the compression of joint *B* is transferred directly by the beam to the column, the only welding at this joint is that required to keep the end of the beam tight against the column face. A fillet *a*, such as shown in Fig. 768, is well adapted to this purpose. Instead, fillets *b*, securing the beam to the shop-welded seat may be used. As the builder's purpose, however, is to secure the beam to the column as directly as possible, fillet *a* is evidently preferable. Another advantage of using fillet *a* is that it forces the erector to push the beam up tight against the column face to permit making the fillet as shown. But it is evident that there is no reason for using both fillets *a* and *b* simultaneously.

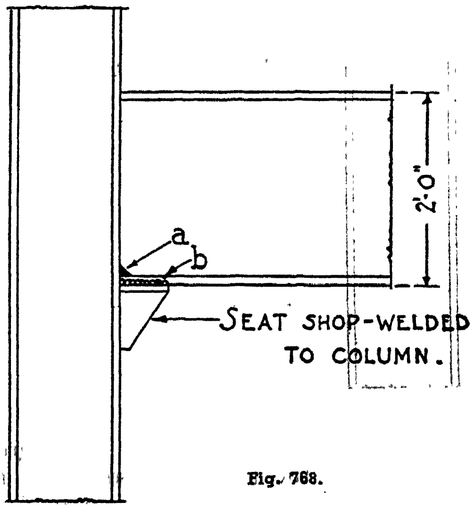


Fig. 768.

In order to facilitate erection, it is necessary to make the length of beams framing between column flanges somewhat shorter than the distance between opposing column faces. If the beams are butted up against the column at one end, there is a gap at the other end of the beams which the connections must bridge, as shown in Fig. 763. For this reason, connections at points *C* and *D* are necessarily different than those at points *A* and *B* respectively.

For continuous action, the stress at *C* is always tension, that is, a pull on the column. The most direct way of making this connection is by means of a plate field welded to the top of the beam and to the face

of the column. This plate bridges the erection gap. The amount of tension that can be developed depends on the size and thickness of the tie plate and upon the welding used.

If a single ½″ fillet *a*, Fig. 769, is used to connect the plate to the column face and the width of the plate is *w*, the tension capacity of the joint will be 5,000 *w* lbs. If $w = 9$, the tension capacity is 45,000 lbs. and the moment value of the connection is 45,000 × beam depth (two feet) = 90,000 ft. lbs., as in Fig. 764.

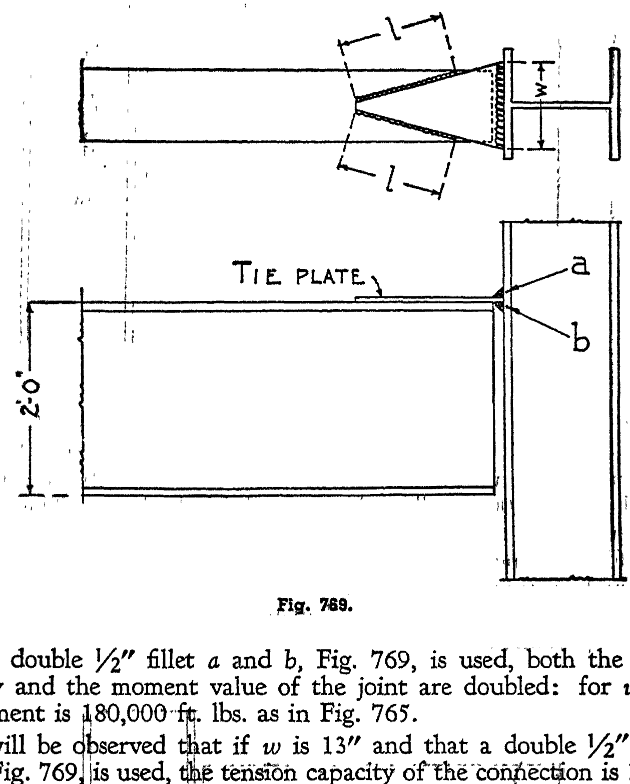


Fig. 769.

If a double ½″ fillet *a* and *b*, Fig. 769, is used, both the tension capacity and the moment value of the joint are doubled: for $w = 9$, the moment is 180,000 ft. lbs. as in Fig. 765.

It will be observed that if *w* is 13″ and that a double ½″ fillet *a* and *b*, Fig. 769, is used, the tension capacity of the connection is 130,000 lbs. and the moment value of the joint is 260,000 ft. lbs., the capacity of the beam. The fillet welds at *l*, Fig. 769, connecting the tie plate to the beam flange must, of course, have strength enough to deliver the desired tension to the column.

Fig. 770 shows the tie plate butt welded, at the V'd joint, to the column. Again, by choosing a plate of suitable thickness and cross-section, any tension and moment values may be developed up to the capacity of the beam.

Suppose a tie plate 14″ × 9/16″ is used: the tension value of the butt weld of the V'd joint is 14 × 9/16 × 16,250 = 128,000 lbs. and the moment value is 128,000 × beam depth (two feet) = 256,000 ft. lbs., the working value of the beam. The strength of the plate just

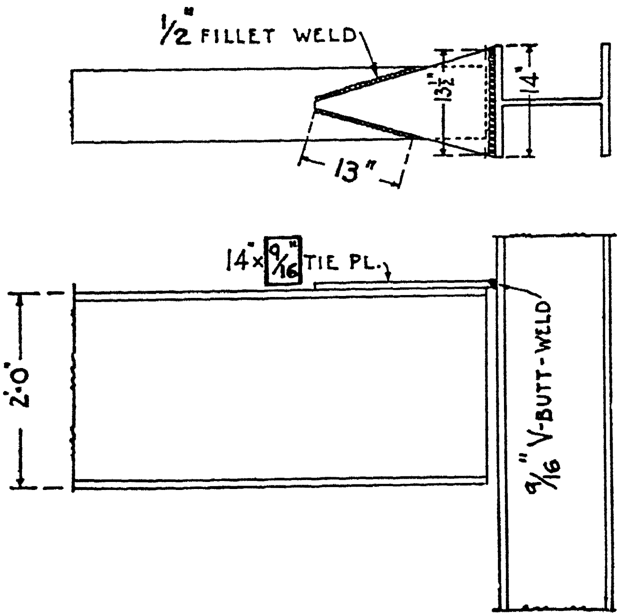


Fig. 770.

beyond the beam's end is $13\frac{1}{2} \times \frac{9}{16} \times 18{,}000 = 137{,}000$ lbs. and its moment is 274,000 ft. lbs. The two ½″ fillet welds, *l*, each 13″ long, have a tension strength of $2 \times 5000 \times 13 = 130{,}000$ lbs. and the moment value is 260,000 ft. lbs., the strength of the beam. There is one more requirement that the above tie plate must fulfill: at the ends of the ½″ fillets connecting it to the beam's top flange, the tie plate must have enough section to handle the entire moment stress. In Fig. 779 it will be shown that the 14″ x 9/16″ plate chosen above does not fulfill this last requirement.

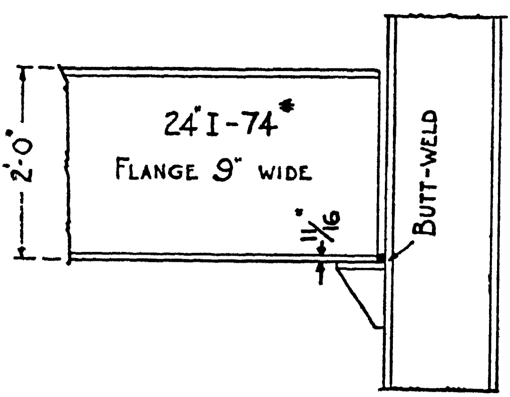


Fig. 771.

For continuous action, joint *D* (Fig. 763) is always in compression, that is, the beam pushes on the column. Fig. 771 shows a square butt weld interposed between the end of the beam's flange and the face of the column. This butt weld in compression has a value of $9 \times {}^{11}\!/_{16} \times 18{,}750 = 116{,}000$ lbs. This gives a moment value of 232,000 ft. lbs., or 91.5% of the beam's strength.

To develop the full strength of the beam, additional flange area is needed at the end of the beam. Fig. 772 shows such additional area provided by means of two 2″ x ¼″ bars shop welded to the bottom flange of the beam. The additional area thus obtained is 1.0 sq. in. As the flange area already provides 6.2 sq. in., the total compression capacity is then $(1.0 + 6.2)\ 18{,}750 = 135{,}000$ lbs. and the moment value is 270,000 ft. lbs., a little more than the beam's capacity.

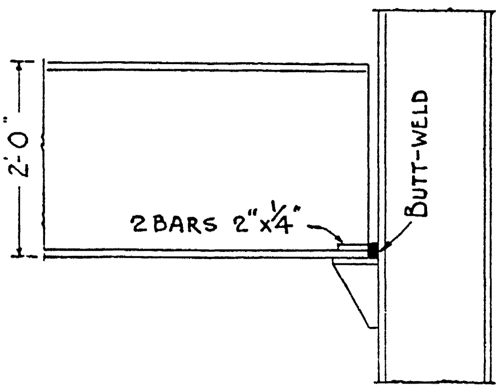


Fig. 772.

It is apparent, however, that the auxiliary bars can be dispensed with by merely connecting the beam to the seat at *D* by adequate fillet welds; the seat itself then furnishes the additional flange section required.

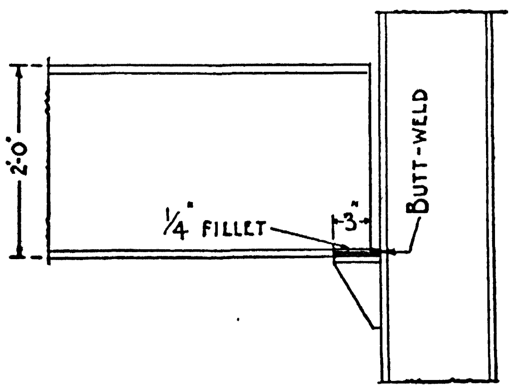


Fig. 773.

Thus, in Fig. 773, the 9" x $1\frac{1}{16}$" butt weld has a moment value of 232,000 ft. lbs. as in Fig. 771. The two ¼" fillets at 2,500 lbs. per lineal inch, have a moment value of 2 × 3 × 2,500 × 2 = 30,000 ft. lbs. The total moment value of the connection is then 232,000 + 30,000 = 262,000 ft. lbs., the working strength of the beam.

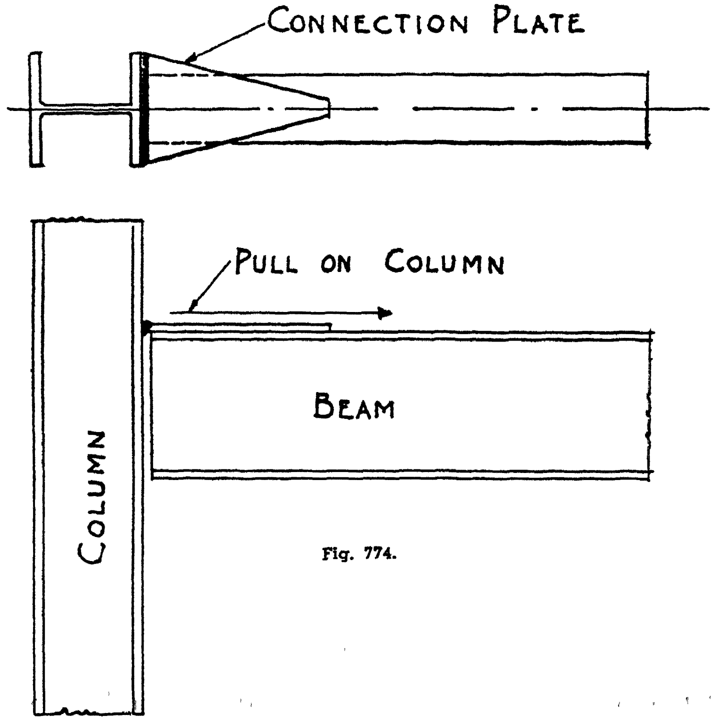


Fig. 774.

Column Web Plates.—The connections of beams to column flanges (Figs. 763 to 773), designed to produce beam continuity, do not show the column's reinforcing plates which are of prime importance in continuous welded connections.

Fig. 774 shows a beam, the top flange of which is welded to the column flange as in Fig. 769. When a load is applied to the beam, it causes flexure, which, as explained previously, causes a pull on the column

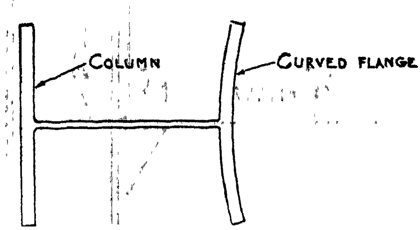


Fig. 775.

opposite the beam's top flange. The resulting strain on the column tends to curve the column flange as pictured in Fig. 775, particularly if the column is a light section.

If the welding happens to be much stronger than the connection plate, (Fig. 775) it may force the plate to take the *same* curvature as the column flange. But if the plate is stronger than the welding, or if the welding is weaker opposite the column web than it is towards the edges of the column flanges, the plate will curve *less* than the column and the weld will break opposite the column web as shown in Fig. 776 and then continue to tear off until the load causing the strain is decreased or removed. The reason for this action is plain: opposite the web, the column is substantially unyielding while the unsupported column flange is free to bend. Consequently, the force pulling on the column is first concentrated on that part of the weld directly opposite the unyielding column web with such intensity that it breaks the weld at that point as the column flange starts to curve. Assuming that the calculations were made correctly and that the *whole weld* was needed to resist the strain, after a part of the weld has been broken, the *remainder* is insufficient to carry the strain and is soon torn off — unless, as stated above, the load is decreased sufficiently or removed.

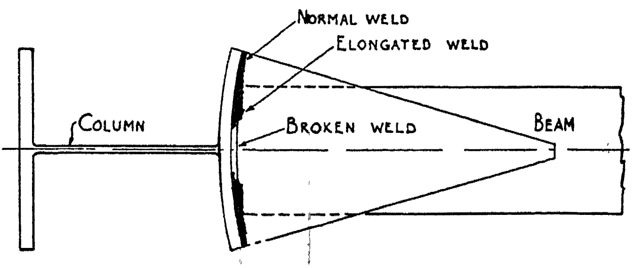


Fig. 776.

It is thus seen that it is of very great importance to so reinforce the column that the flange will *not curve* as the strain is applied.

It has been found that the simplest column reinforcement consists in shop welding plates alongside the column web as shown in Fig. 777. The welding at *a* must be practically equal to that at *b*. Since the function of the reinforcing plates is to stiffen the column flanges and since the stiffest element of the column is the web, it follows that the welding of the reinforcing plates to the column web should be very substantial. In the case of columns to which a beam frames from one side only, as in Fig. 774, these reinforcing plates should be full-welded to the column web. When there are two beams, as in Fig. 777, of substantially the same size, it is frequently only necessary to tack-weld the reinforcing plates to the column web. If the two beams are of disproportionate size, the case is much the same as if only one beam were framed to the column.

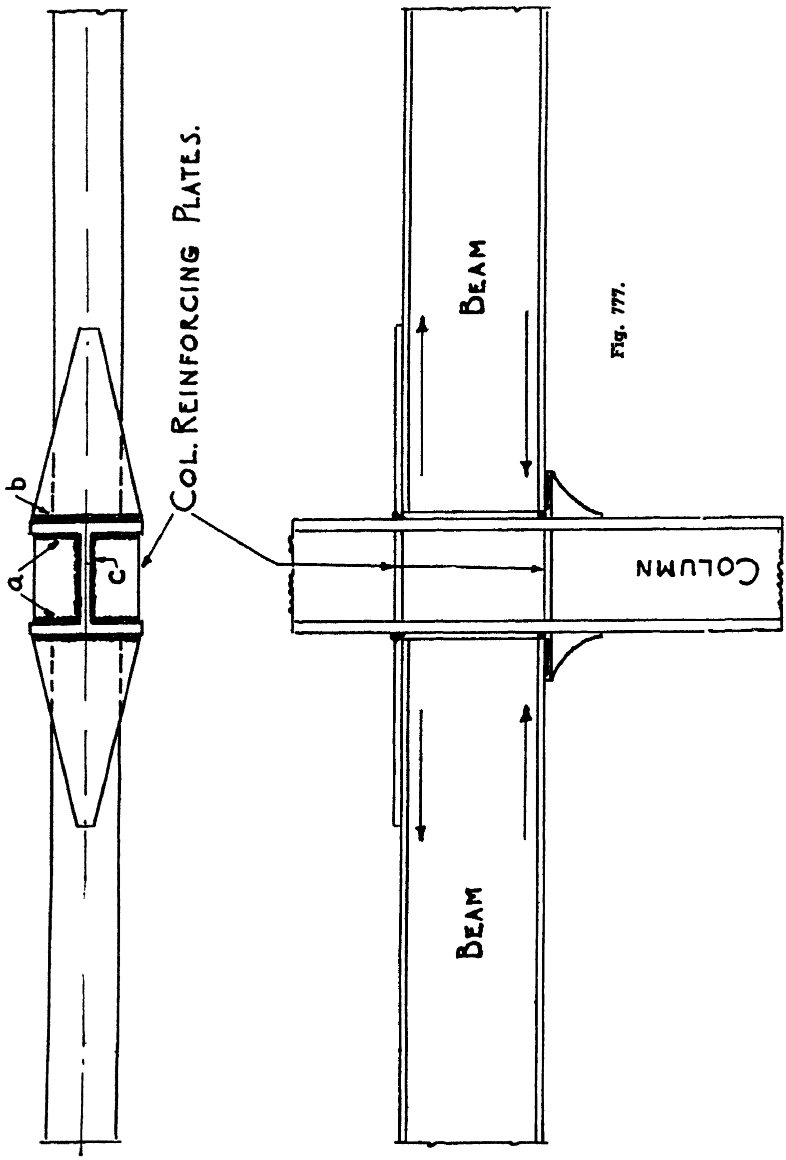


Fig. 777.

In modern riveted connections, the usual attachment for beam continuity consists of split I-beams (Fig. 778). The flange of the split beam must, of course, be thick enough to keep its shape when the flexure of the floor beam causes a pull on the rivets connecting the split I-beam to the column; but, in addition, the tee formed by the split beam must be sufficiently strong to reinforce the column flange effectively to prevent it from curving.

It will then be observed that the problem of keeping the column flange square with the web and preventing curvature in the column requires just as much care with riveted as with welded connections. The

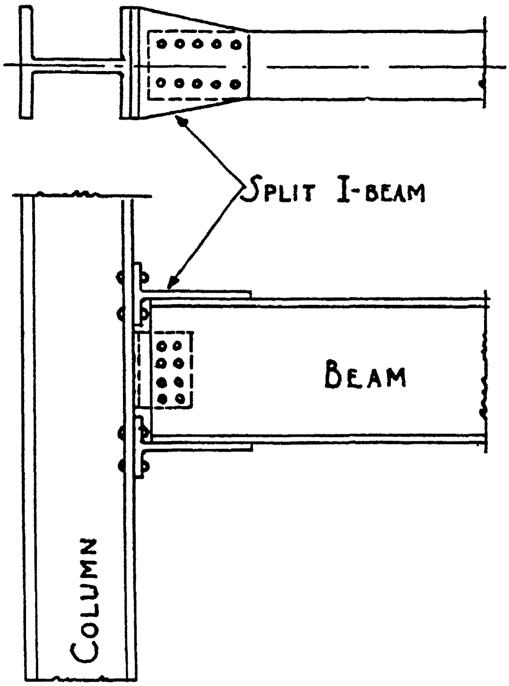


Fig. 778.

solutions differ, but the same condition exists and must be provided for in either case.

Connection Plates.—The proportions of connection plates depend on the stresses they are required to carry. Their shape depends on their position. Fig. 779 shows a triangular connection plate. This figure is similar to Fig. 770. If a 14 x $\frac{9}{16}''$ triangular tie plate is used, the tension value of the butt weld is 128,000 lbs. and the moment value, 256,000 foot lbs.; the two $\frac{1}{2}''$ fillet welds have a tension value of 130,000 lbs. and their moment value is 260,000 foot lbs.; the strength of the connection plate beyond the beam's end is 137,000 lbs. Its moment value is 274,000 foot lbs.

Now consider a section through this connection plate at the ends of the fillets which join it to the top flange of the beam—Section XX, Fig. 779. Here the plate is $8\frac{1}{4}''$ wide. The entire stress to be transmitted from the beam flange to the plate has been delivered by the two $\frac{1}{2}''$ fillet welds. Therefore, *at this section* the plate must be sufficiently strong to carry alone the entire transmitted stress to the column. The strength of the plate at this section is $8 \times \frac{9}{16} \times 18{,}000 = 81{,}000$ and the moment value is $81{,}000 \times 2 = 162{,}000$ foot lbs. or only 63 per

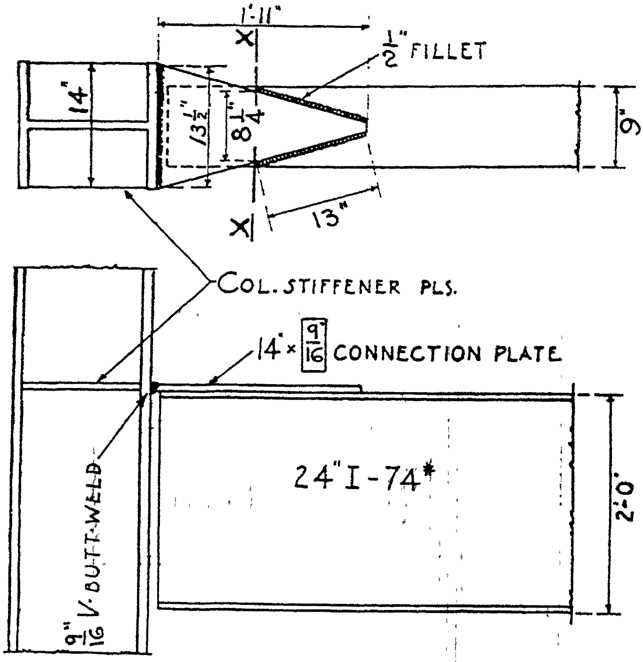


Fig. 779.

cent of the beam's strength. To develop the full strength of the beam (256,000 foot lbs.), the plate should be $\frac{7}{8}$" thick, $(\frac{7}{8} \times 8\frac{1}{4} \times 18{,}000) \times 2 = 260{,}000$ foot lbs.

With a $\frac{7}{8}$" plate, however, the length of butt weld required at the column is $128{,}000/16{,}250 \times \frac{7}{8} = 9$", Fig. 780, and if a $\frac{5}{8}$" fillet weld is used to secure the connection plate to the beam flange, the length of fillet required is $128{,}000/2 \times 6250 = 10\frac{1}{4}$". Just beyond the fillet welds, the strength of the plate is $8 \times \frac{7}{8} \times 18{,}000 = 126{,}000$ lbs. and its moment value is $126{,}000 \times 2 = 252{,}000$ foot lbs., the value of the beam. This connection plate is both narrower and shorter than that shown in Fig. 779.

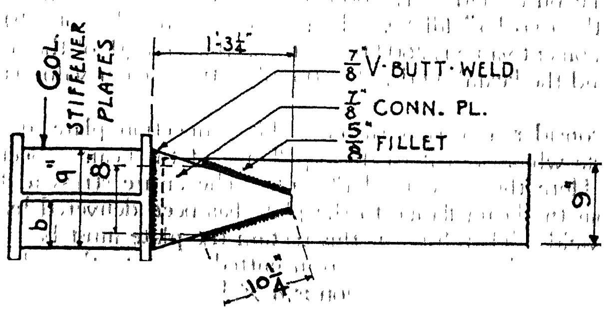


Fig. 780.

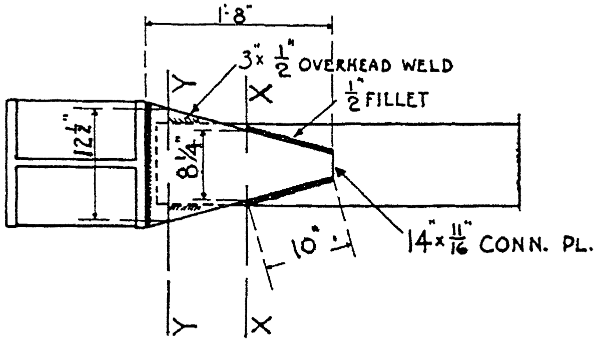


Fig. 781.

If the welding is done as shown in Fig. 781, a 14 x 11/16" plate is adequate. The welding here differs from that shown in Fig. 779 in that, instead of using two 1/2" fillets 13" long, the fillets welded "flat" are 10" long and they are supplemented by two 3" x 1/2" overhead fillets located as shown. At Section *XX* the amount of tension taken into the plate by the two 10" fillets is 2 × 10 × 5,000 = 100,000 lbs. and the value of the plate at this section is 8¼ × 11/16 × 18,000 = 102,000 lbs. At section *YY*, the entire beam tension capacity, 128,000 lbs., has been delivered to the plate which is here 12½" wide. The capacity of the plate at this section is 12½ × 11/16 × 18,000 = 154,000 lbs. It will be noted that the narrower the V'd butt weld connection, the smaller may the column stiffeners be made. (See *b*, Fig. 780.)

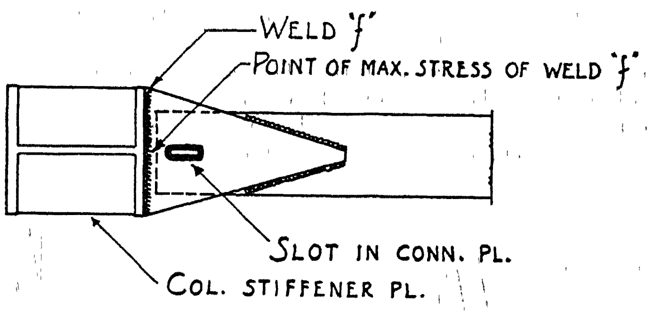


Fig. 782.

It is apparent that instead of the short overhead welds, a slot weld might be made through the connection plate as shown in Fig. 782. Attention has been called to the need of column stiffeners to keep the column flanges from curving. Tests have shown that, under high stresses, a column flange reinforced with stiffeners will sometimes distort just enough to produce a stress concentration in weld *f*, Fig. 782, opposite the column web. A slot weld, located as in the figure, evidently increases the stress in weld *f* directly opposite the column web where there may already exist a stress concentration due to column distortion. This arrangement should therefore be avoided.

Welding for Stiffness.—The principal function of stiffness in a structure is to resist side sway from wind or from earthquake. If the lateral force is operating from the left toward the right, as shown in

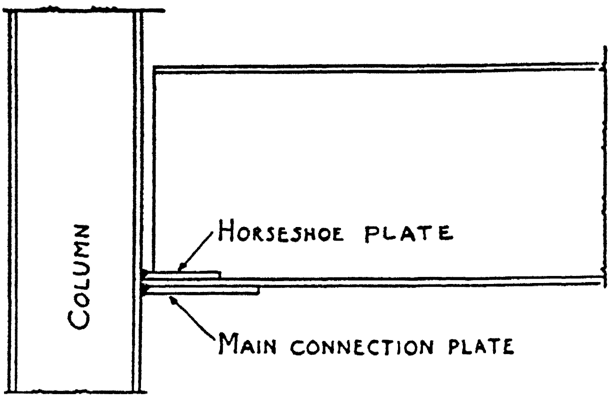


Fig. 783.

Fig. 784, joints *A* and *D* are in compression and joints *B* and *C* are in tension. If the lateral force is operating toward the left, Fig. 785, joints *A* and *D* are in tension and joints *B* and *C* are in compression. Therefore, when welding for lateral stiffness, all joints must be able to resist both tension and compression, while as noted before, when welding for continuous action only, top joints are always in tension while bottom joints are always in compression.

Fig. 786 shows a 24"-74 lb. beam intended for lateral stiffness (compare this with Fig. 763, Page 548. The joint *A* is in compression. If the beam butts the column perfectly, the compression can be taken by bearing of the beam flange against the column. If this bearing is imperfect due to the beam being cut ragged or if the beam is not pushed up tight against the column, the fillet welds shown previously, Figs. 764 and

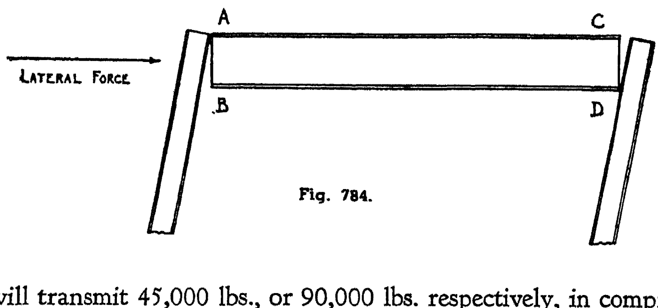


Fig. 784.

765, will transmit 45,000 lbs., or 90,000 lbs. respectively, in compression just as well as in tension, since the welds are fillets. The butt welds shown in Figs. 766 and 767, have greater compression strength than the tension values calculated previously, since the unit stress allowed for compression is 18,750 lbs. per sq. in. against 16,250 lbs. per sq. in. for tension.

Fig. 786 shows an erection clearance at C. If this clearance were at *A* instead of at C (see Fig. 787) and a plate connection of the type shown in Figs. 781 or 780, were used, the fillet welds connecting the

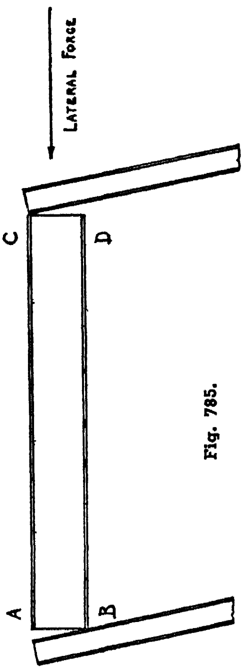


Fig. 785.

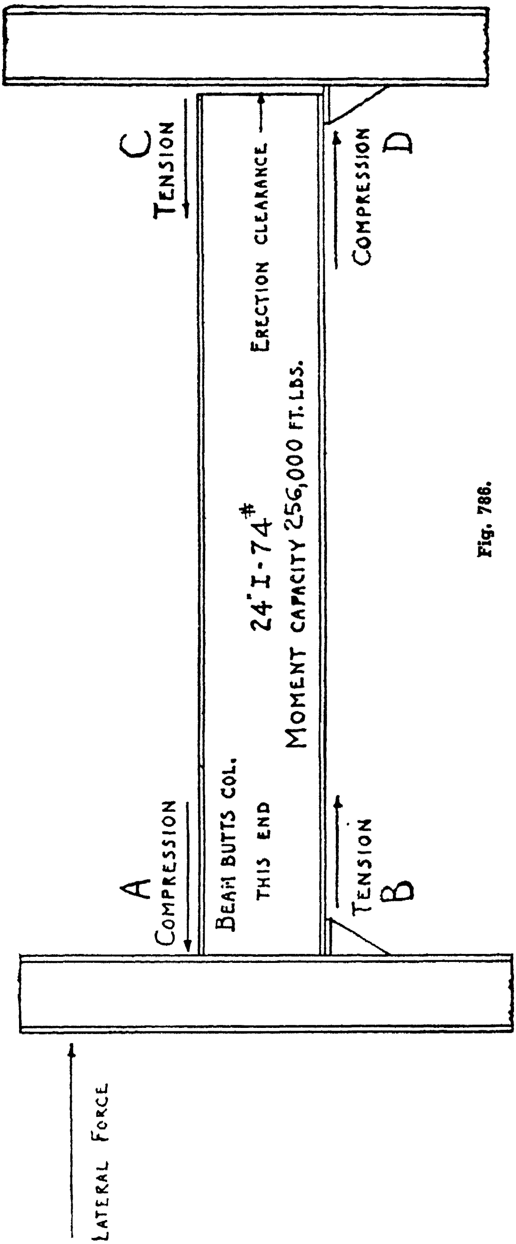


Fig. 786.

plate to the beam's top flange will transmit 128,000 lbs. in compression as well as in tension while the V-butt welds to the column will readily transmit that stress in compression since they are adequate in tension.

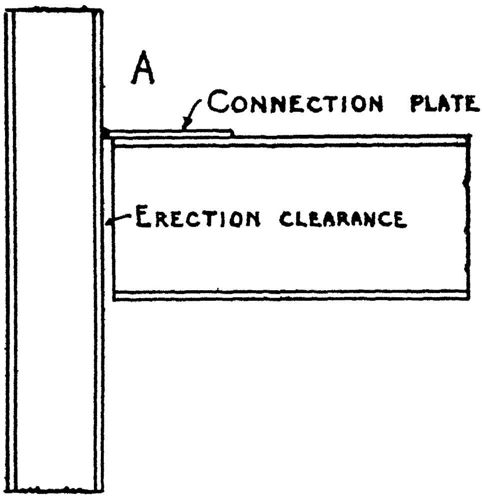


Fig. 787.

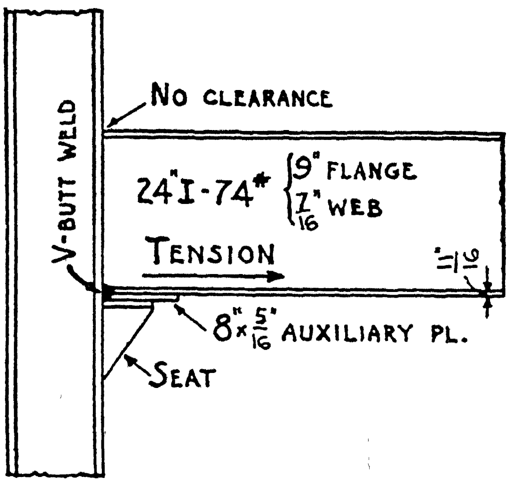


Fig. 788.

It follows from these observations that the strength provided at tension connections for a given requirement is always ample to take care of a reversal to compression.

The converse, however, is not true: the compression connections shown in Fig. 768, and those shown in Figs. 772 and 773, are ample so long as the stress is compression but they are inadequate if the stress reverses to tension as is required at joint B, Fig. 786.

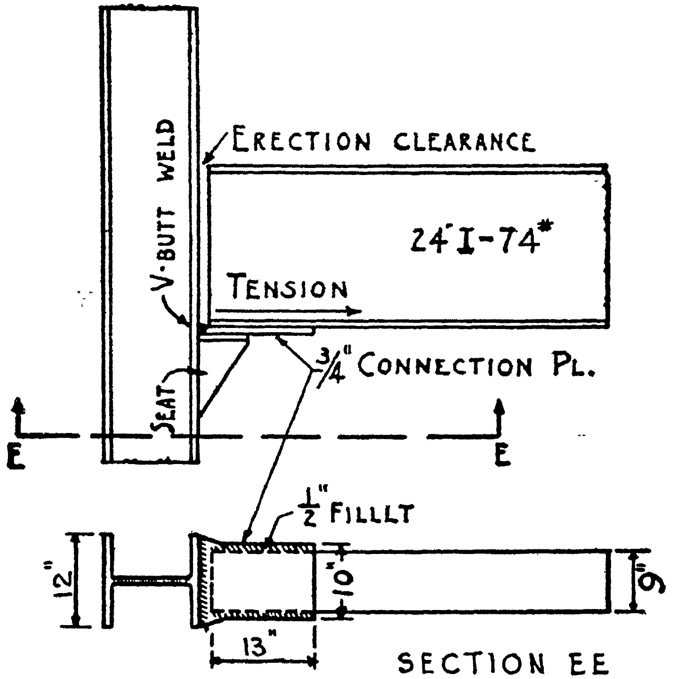


Fig. 789.

The simplest tension connection, if the beam is butted to the column face, is that shown in Fig. 788: an auxiliary plate is welded to the beam flange; both beam flange and auxiliary plate are then bevel-cut so as to give the required section for the field V-butt weld. In Fig. 788, deducting the thickness of the web, the beam flange has an area $8\frac{9}{16}'' \times \frac{11}{16}'' = 5.87$ sq. in.; the auxiliary plate has an effective area $7\frac{1}{2}'' \times \frac{5}{16}'' = 2.33$ sq. in. or a total area of 8.2 sq. in., which at 16,250 lbs. per sq. in. allowable in tension under the Fusion Code equals 133,000 lbs. This gives a moment value of 266,000 ft. lbs., which exceeds slightly the capacity of the beam.

If there is an erection clearance, a plate is required as shown in Fig. 789. This plate should be wider than the beam flange so as to provide a welding edge along the bottom flange of the beam. In the case shown, the strength of the connection plate is $10\frac{1}{2} \times \frac{3}{4} \times 18{,}000 = 142{,}000$ lbs. The $\frac{1}{2}''$ fillet weld's value is $2 \times 13 \times 5{,}000 = 130{,}000$ lbs. The strength of the V-butt weld is $12 \times \frac{3}{4} \times 16{,}250 = 146{,}000$ lbs.

In Figs. 788 and 789, the function of the seat is to land the beam when erected and to carry the beam's vertical load.

Heavy Rolled Sections—In rigid end-connected beams, there is a point near each end called the point of inflexion, where there is no flange stress, only shear (vertical stress). By taking advantage of this fact, the beams may be ordered to fit between the opposing column faces as usual and then flame-cut into three sections, as shown in the

accompanying details. These cuts may be made on approximately a 60 degree bevel at points *A* and *B* as shown in Fig. 790, or made square, as shown in Fig. 791. If square cut, the beam sections are all ordered from the mill, allowance being made for the customary mill tolerances in shearing.

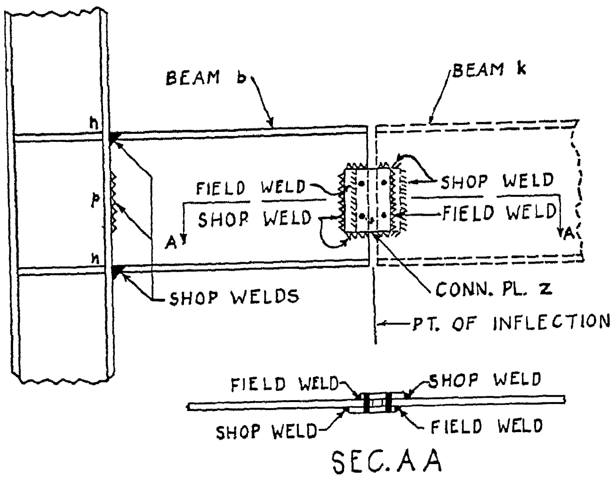


Fig. 791.

The short end sections of the beams are all welded to the columns in the shop where the work can readily be placed in the most advantageous position for welding, where protection from the elements, accessibility to the work and to the welding machines all favor the best workmanship at lowest costs. By using the shielded arc under those conditions it is entirely safe to connect beam flanges directly to columns without the addition of auxiliary plates (see Fig. 767, and Fig. 788). The great ductility of shielded arc welds insures safety in handling and erection of the columns with stub beams attached, without danger of cracked welds. Thus the heaviest beams can be fully developed at their column connection without the use of any split beams and large rivets or field-welded bridging plates or auxiliaries.

The center section of the beam is field-welded or bolted to the stub ends after the columns are erected. Since the only stress to be provided for at the field joints is shear, the flanges of the stub sections are not welded to the flanges of the middle section. Only a relatively light web connection is needed, thus reducing erection costs to a minimum.

In Figs. 790 and 791, the stub ends, marked "Beams *b* and *d*," are shown shop-welded to columns *c* and *e* respectively at points *n* and *p*. The welds marked *p* are fillet welds proportioned only for the reaction to be brought to the column by the beam. The welds marked *n* are fixation or "continuity" welds having a cross section equal to the full cross section of the beam flange, without adding any auxiliary plates, if made in the shop with the shielded arc, as noted above.

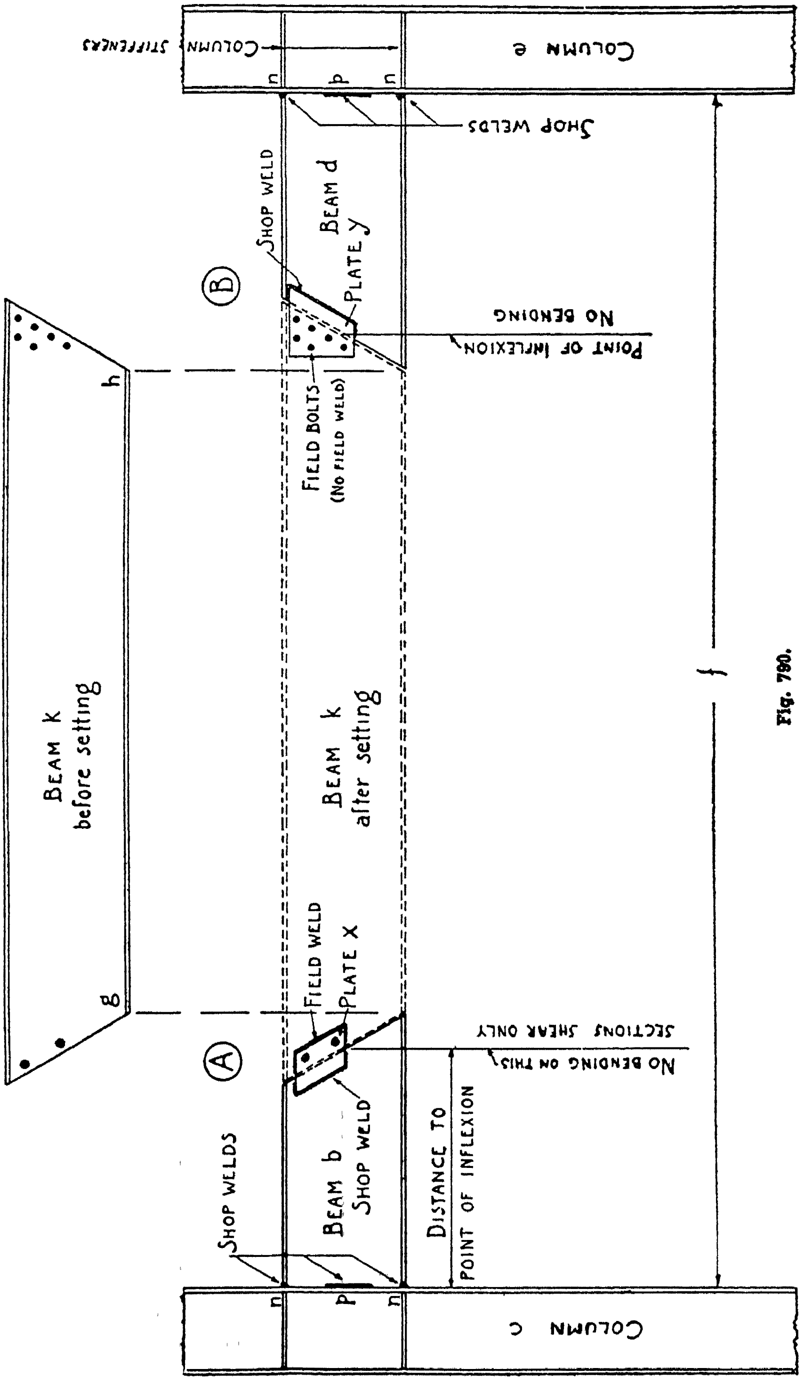
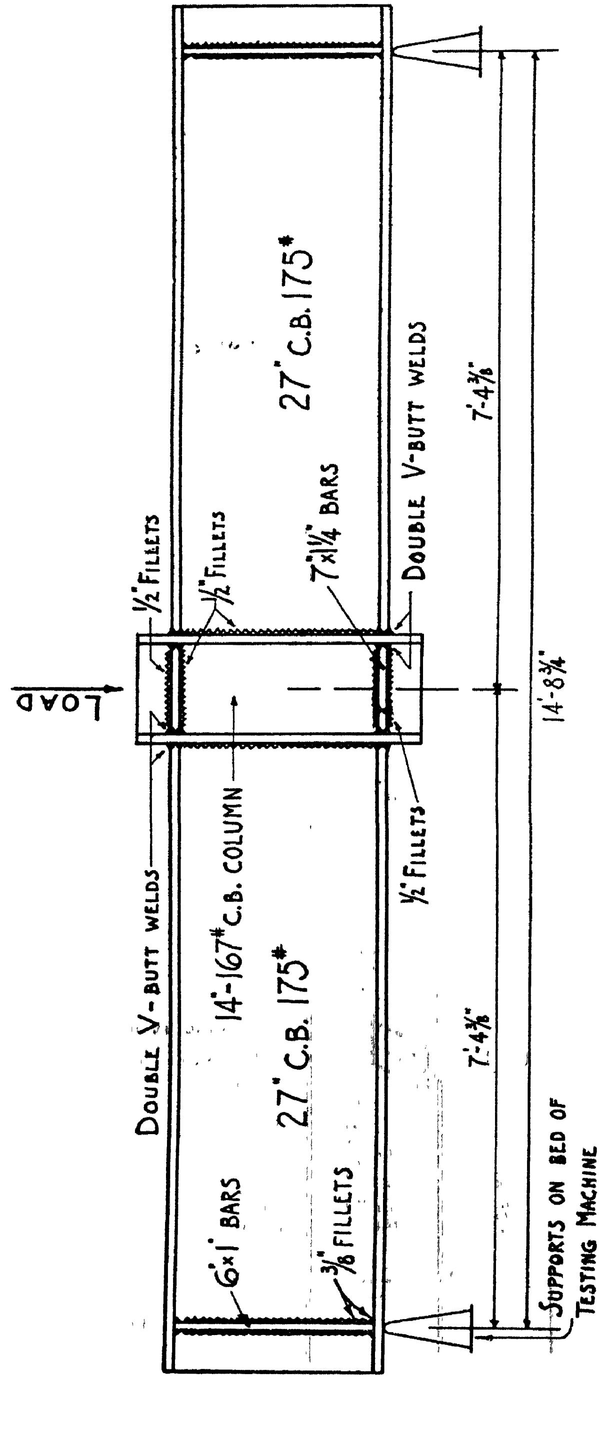

Column e
Column stiffeners
Shop welds
Shop weld
Beam d
Plate y
No bending
Point of inflexion
Field bolts
(No field weld)
Beam k
before setting
Beam k
after setting
Field weld
Plate x
Sections shear only
No bending on this
Shop welds
Beam b
Shop weld
Distance to
point of inflexion
Column c
A
B
g
h
n
p
f

Fig. 780.



LOAD
27" C.B. 175#
27" C.B. 175#
14"-167# C.B. COLUMN
DOUBLE V-BUTT WELDS
DOUBLE V-BUTT WELDS
1/2" FILLETS
1/2" FILLETS
1/2" FILLETS
7"x1 1/4" BARS
6"x1" BARS
3/8" FILLETS
7'-4 3/8"
7'-4 3/8"
14'-8 3/4"
SUPPORTS ON BED OF TESTING MACHINE

Fig. 792.

In Fig. 790, the center section of the beam, marked *k*, is shown hoisted up, ready to drop into the position indicated by the dotted lines. Two types of field connections are shown: at *A*, two plates marked *x* are shown shop-welded to beam *b*, one on each side of the web. Beam *k* is connected to plates *x* by two bolts which serve to set the beam accurately. Later, beam *k* is welded to plates *x* as shown.

At *B*, two plates marked *y* are shop-welded to beam *d* one on each side of the web. Beam *k* is set and full-bolted at once to these plates, without any field-welding. The end bevel cuts permit the web of beam *k* to drop between the pairs of plates *x* or *y* while the flange of beam *k*, at points *g* and *h*, clears plates *x* and *y* as beam *k* is dropped into position.

In Fig. 791 all beam sections are shown square cut. This is preferable to skew cuts. One connection plate is shop-welded to beam *k* (shown on far side, Fig. 791) and one plate is shop-welded (near side, Fig. 791) to beam *b*. After field bolting (2 bolts in each beam section, as shown) the far plate is field-welded to beam *b* and the near plate is field-welded to beam *k*.

Test on Heavy Sections—The strength and reliability of shielded arc-welded beam to column connections described previously has been demonstrated by test of typical full size connections. The test was conducted by one of the country's leading universities in their structural testing laboratory.

The test specimen was constructed as shown by Fig. 792. Stiffeners were located on both sides of the beam sections and in the column web. All welds were made by the shielded arc with equipment shown in Fig. 793. A closeup view of the beam to column connections is shown in Fig. 794.

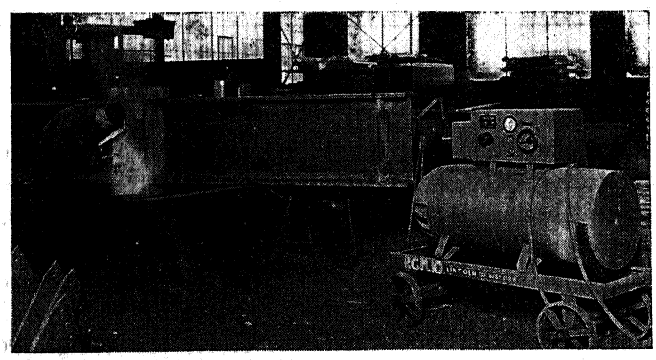


Fig. 793. Shielded arc welding of test specimen.

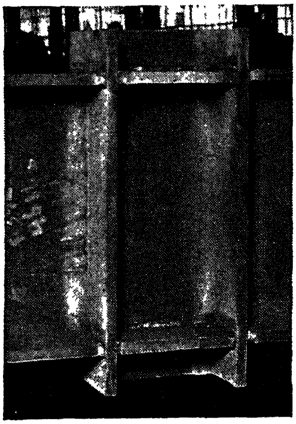


Fig. 794. Welded beam to column connections in specimen prior to test.

A million pound testing machine was used by the university for loading the specimen. Fig. 795 shows the specimen under the initial load of 5,000 lbs. in testing machine. The data and notations in the following table are made from the university's report of test:

Central Load Pounds	Calculated Deflection	Observed Deflection	Notes on Beams	Notes on Welding
200000	0.12"	0.13"	Within elastic limit	All welds intact
250000	0.15"	0.18"	Within elastic limit	All welds intact
300000	0.17"	0.22"	Within elastic limit	All welds intact
350000	0 20"	0.28"	Passing elastic limit	All welds intact
400000	0.23"*	0.38"	Beyond elastic limit	All welds intact
600000	0.34"*	6.00" Approx.	Near failure	All welds intact
615000	—.—	—.—	Top flange buckling	All welds intact

*Deflection calculated as if beams were still within their elastic limit.

The calculated and the observed deflections agreed closely until the load approached 350,000 lbs. At that load, the divergence shows that the load was beginning to cause permanent distortion. At 400,000 lbs. the observed deflection was 70% greater than it would have been if the elastic limit had not been passed. From then on, the deflection increased very rapidly until, at a load of 600,000 lbs., it was eighteen times that of a beam still within the elastic limit. Fig. 796 shows specimen under load of 600,000 lbs.

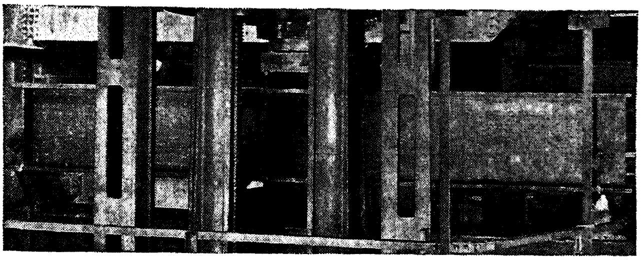


Fig. 795. Specimen under initial load of 5,000 lbs. in million pound testing machine.

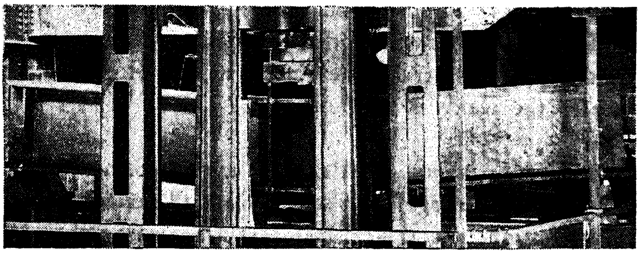


Fig. 796. Under 600,000 lb. load.

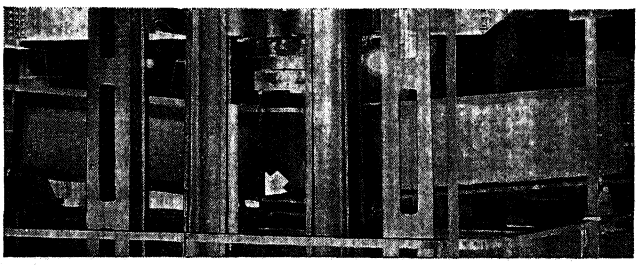


Fig. 797. Under 622,100 lb. load. Arrow points to connection which failed at this loading.

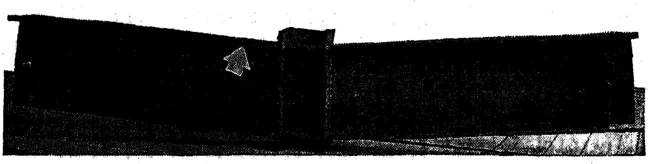


Fig. 798. Specimen after test. Arrow shows location of flange buckling which started at loading 615,000.

At 615,000 lbs., the top flange of one beam began to buckle upwards about one foot away from the column as indicated by arrow, Fig. 798. This shortened the distance between centers of tension and compression, intensifying the tension in the bottom flange and connecting welds.

The loading was still increased. At 622,100 lbs., with a deflection of 6¼", a butt-weld securing a lower column stiffener to the inside of the column flange broke (see arrow, Fig. 797) together with the tapered end of the column stiffener. The fracture was widest at the edge of the column flange and decreased to a hair crack next to the column web. Fig. 798 shows specimen after completion of test.

From the above consideration, it is apparent that the tension butt-weld held on until the stress exceeded its ultimate capacity, i.e., in the vicinity of 70,000 lbs. per sq. inch.

It has sometimes been said that steel, by its slow distortion under excessive loads, gives ample warning of impending danger while a weld breaks suddenly. And it will readily be admitted that, so long as welds break suddenly only after the steel itself has distorted and failed, full confidence in the welds is warranted.

Examples of Economy of Welded Design—Sometimes reinforced concrete has an advantage over steel, when all concrete members are designed as continuous and steel members are considered as freely supported at their ends. However arc welding furnishes a means of making steel members continuous at a cost which often makes the use of continuity in steel work advantageous.

Fig. 799 shows a beam loaded with 1920 pounds per foot on a span of twenty feet. Calculated as a freely supported beam without any continuity, the center bending moment would be 96,000 foot pounds. Figured the way reinforced concrete would be, the center moment is 64,000 foot pounds, requiring a 14"-30 lb. beam, while the 96,000 foot pounds above require a 14"-43 lb. beam, or 43% more steel.

In concrete, in order to figure the smaller moment, it is stipulated in building codes that a moment also of 64,000 foot pounds be developed at the beam's ends. A method of accomplishing this in steel is shown in Fig. 800. Here, an end-beveled 6" × ⅝" tie plate is field-welded to the top flange of the beam and butt-welded to the column. The end of the bottom flange is butted up against the column by a 6¾" x ⅜" field weld between the end of the beam and the column and by two fillet welds to the seat.

The 16 inches of ⅜" fillet weld, as shown, have a value of (3750 × 16 × 14/12) = 70,000 foot pounds.

The butt weld to the column has a value of [6 × ⅝ × 14/12 × 16,250] = 71,000 foot pounds. The value of the ⅜" butt weld at the end of the bottom flange is 18,750 × 6¾ × ⅜ × 14/12 = 55,200 ft. lbs., and that of the two 3" x ¼" fillets to the seat is 2 (3 x 2,500) 14/12 = 17,500 ft. lbs., a total, for the bottom flange, of 72,700 ft. lbs.

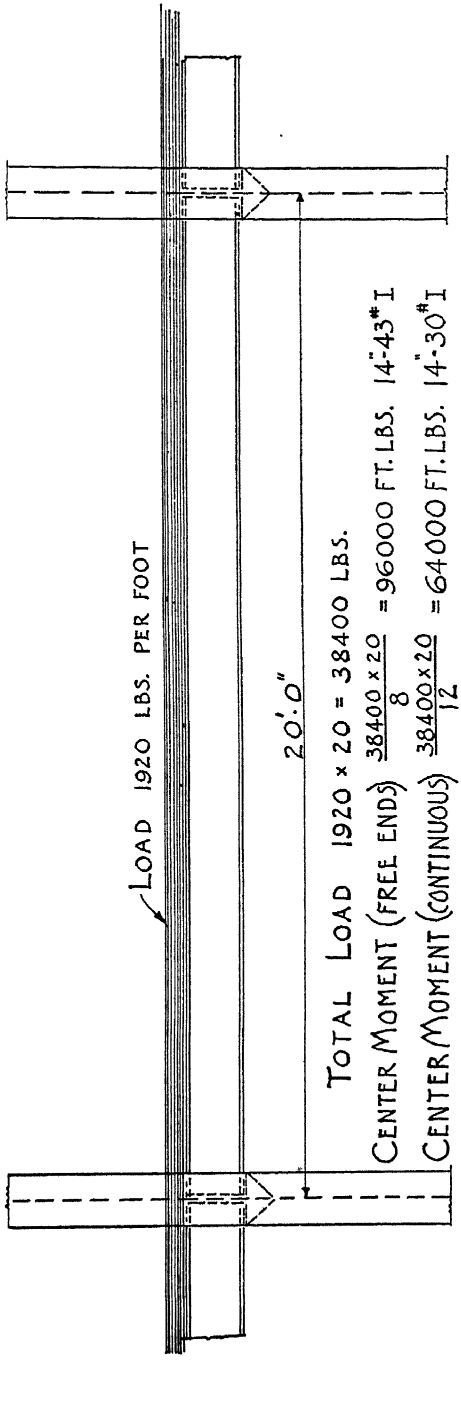

LOAD 1920 LBS. PER FOOT
20'.0"
TOTAL LOAD 1920 × 20 = 38400 LBS.
CENTER MOMENT (FREE ENDS) 38400 × 20 / 8 = 96000 FT. LBS. 14"-43# I
CENTER MOMENT (CONTINUOUS) 38400 × 20 / 12 = 64000 FT. LBS. 14"-30# I

Fig. 799.

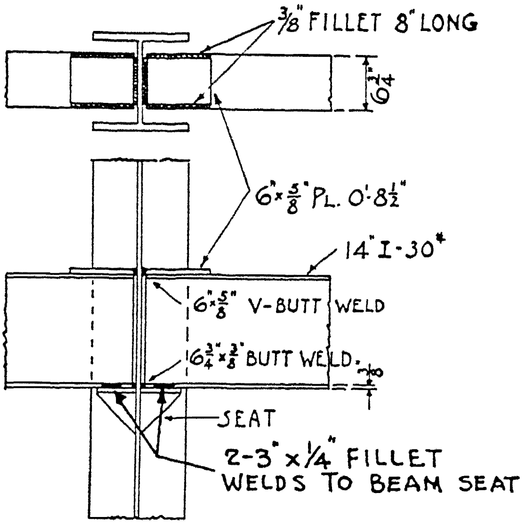


Fig. 800.

Whenever reinforced concrete slabs are used as flooring in steel-frame buildings, a simple method of obtaining continuity for steel beams is that shown in Fig. 801. Since the steel beams themselves are encased in concrete at the time the slabs are poured, the steel and the concrete act as a unit, as proved by the tests made at the University of Toronto and reported in Bulletin No. 5 of that institution. If, therefore, the bottom flange of the steel beam is butt welded up against the column so as to resist the compression, the tension at the top may be taken across the column from one beam to the beam opposite by tension bars in the top of the concrete itself. In Fig. 801, the four 1" round rods have a value of $4 \times .7854 \times 18000 \times \frac{14\frac{1}{2}}{12} = 68{,}000$ ft. lbs.

In this method, the steel is built in quite the usual fashion after which the bottom flange of the beams is butt welded to the columns. The tension rods are placed along with the concrete construction. Thus the floor beam tonnage is reduced as much as 25% to 30%.

Slotting Column Web to Secure Continuous Beams — Another point in connection with continuous beams secured to column webs is that of slotting the column web. It is customary to make columns in two or three story lengths. The shaft is designed for the bottom story load. The section is overstrong for the upper story or stories so a slot can be made in such stories without effect on the column's strength. In the bottom story, at the point where a slot is proposed, there are beams to be

attached to the column; such beams brace the column laterally; at points of lateral bracing there is no reason why a higher stress than the usual column allowance may not be used.

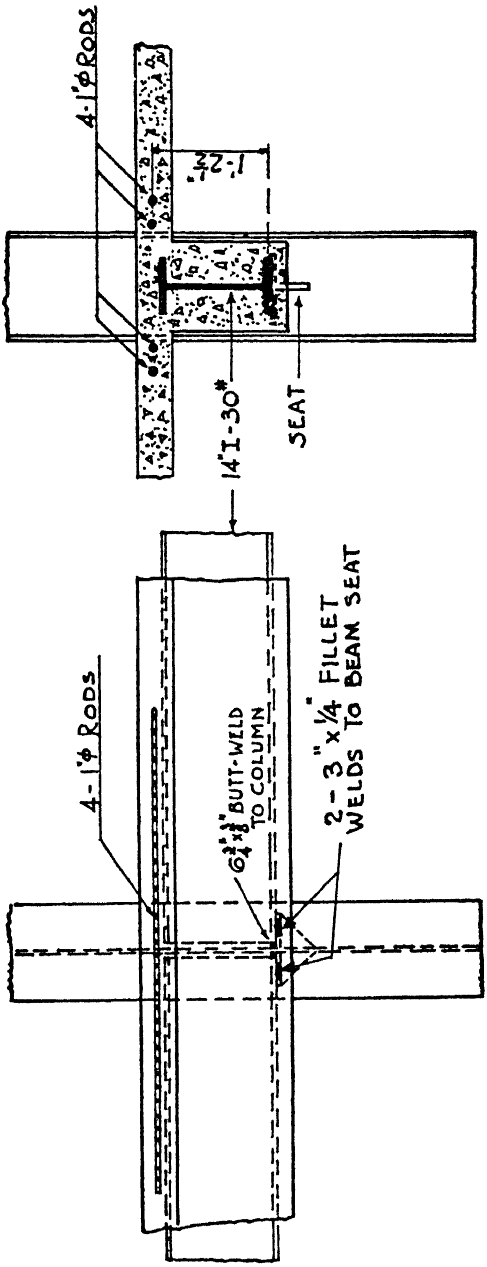


Fig. 801.

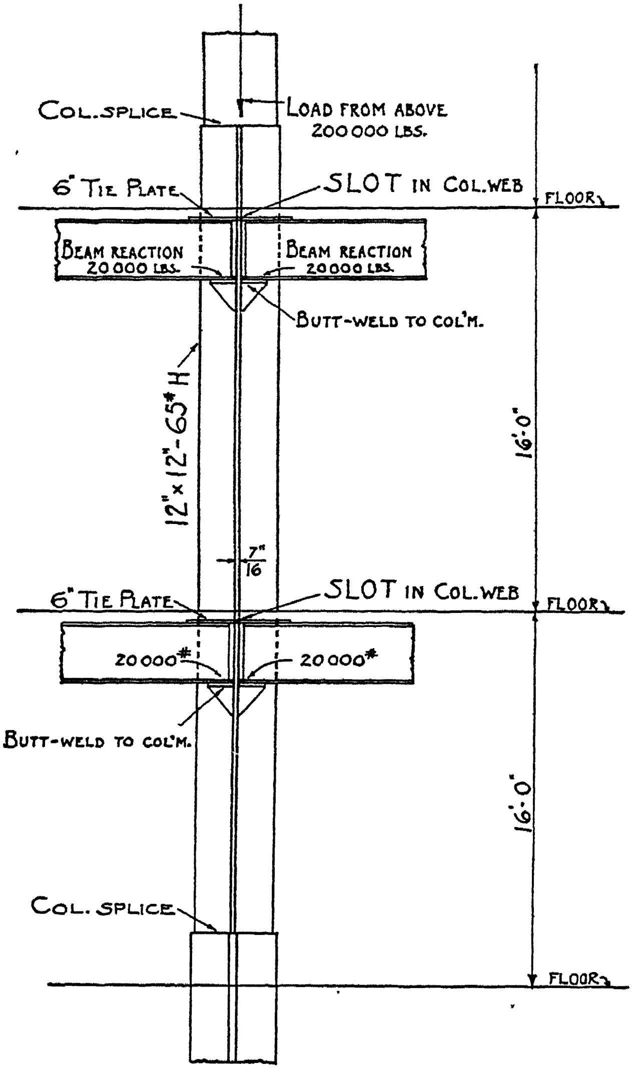


Fig. 802.

In the column formula—

$$f = \frac{18000}{1 + \dfrac{l^2}{18000 r^2}}$$

the denominator decreases the numerator by an amount proportioned to the value l/r. As a consequence, the greater the danger from lateral flexure, the smaller the allowable value, f, on the column shaft. But, at

points of lateral bracing, there is no reason for decreasing the numerator since there is no lateral flexure to take into account any more than in the compression flange of a beam properly side-braced.

In Fig. 802, a two-story column is shown. The load from each floor is 40000 lbs. and there is a load of 200000 lbs. accumulated from above. The column section shown has an area of 19.1 sq. in.; its allowable load on a 16 foot height is 281000 lbs. or 14750 lbs. per sq. in. which makes proper allowance for lateral flexure. The slots shown in the web are 6½″ wide; the web of the column is 7/16″ thick so the slot deducts 2.85 sq. in. leaving 16¼ sq. in. net. Now 281000/16¼ = 17300 lbs. sq. in., which is not an excessive stress directly at a point of efficient lateral bracing.

Slotting the column web permits making an economical and rapid connection between opposite beams; this in turn allows the use of steel on the same basis as concrete beams.

Reinforcement of Columns.—Steel columns are generally H-shaped. Their strength, measured by the radius of gyration, is about twice as great on the axis parallel to the flanges as on that parallel to the web.

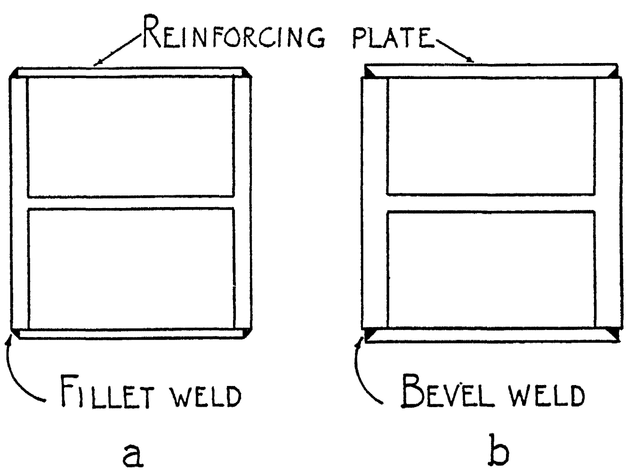


Fig. 803.

When it is desirable to even up the strength of columns about their two axes, a simple expedient consists in welding a suitable plate to the edges of the column flanges, as shown in Fig. 803. If the plate is light, fillet welds are used to attach it to the column. If thick plates are to be added to the column, the plate edges should be bevel cut before welding.

As the strength of the column increases rapidly on the axis parallel to the web, it decreases, but in a much smaller proportion, on the axis parallel to the flanges as shown in the following table:

VALUES OF RADIUS OF GYRATION OF 14″—87 LBS. COLUMN SECTION WITH AND WITHOUT REINFORCING PLATES

	No plate	2 pls. 13x3/8	2 pls. 13x1/2	2 pls. 14x1/2	2 pls. 14x5/8
R1-Axis parallel to flanges.	6.15	5.60	5.45	5.48	5.38
R2-Axis parallel to web.	3.70	5.00	5.30	5.35	5.60

With 14″ x 1/2″ plates, the radius of gyration R1 decreases 11% while R2 increases over 44%, thus the strength of the column becomes practically the same about both axes.

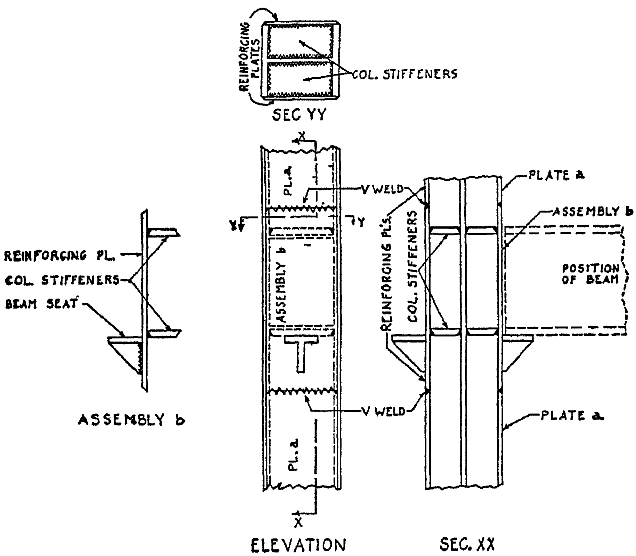


Fig. 804.

Thus when large or heavy beams are framed to columns on their normally weaker axis and the columns are required to resist bending in two directions simultaneously, such columns may readily be strengthened for any desired height and the strong connections to column flanges, described previously, can be utilized.

In Fig. 804, the column reinforcing is shown to consist of plates *a* and assembly *b*. This assembly consists of four elements: a section of reinforcing plate, two column stiffeners and a beam seat. When this

assembly has been shop-welded together, it is inserted into the column and welded thereto. Plates *a* are then shop-welded to the column and to the ends of the reinforcing plates of assembly *b*. The result is now exactly the same as if the beam were to be attached to column flanges and is of equal strength.

Beam Connections.—In designing beam to beam or beam to girder connections, the shop punching of the main members should be eliminated as much as possible, as this will materially reduce fabricating costs, inasmuch as the beams or girders are large and heavy and cost considerable to handle.

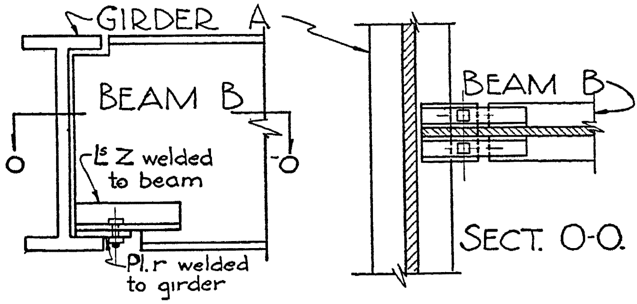


Fig. 805.

Fig. 805 shows a beam to girder or beam to beam connection, both members being of the same depth. As shown, the angles Z are punched and shop welded to beam *B*. The punched flange plate *r* is shop welded to the flange and web of girder *A*. Temporary connection is made in the field by bolting the angles Z to plate *r*.

Where beams are situated at different elevations a detail such as shown in Fig. 806 may be used. This connection is of the same type as shown in Fig. 805. Observe that this type of connection is adapted to girders having sloping flanges as well as to girders with square flanges; it is merely necessary to weld the connection angles of the beam at the same slope as the girder flange.

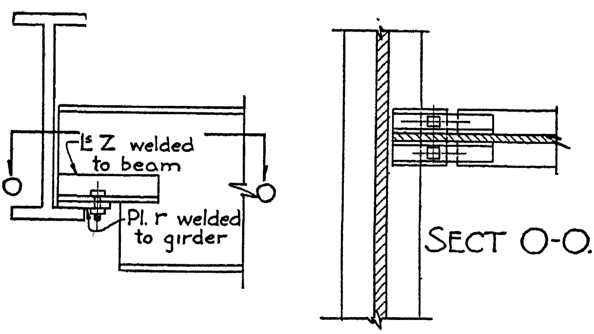


Fig. 806.

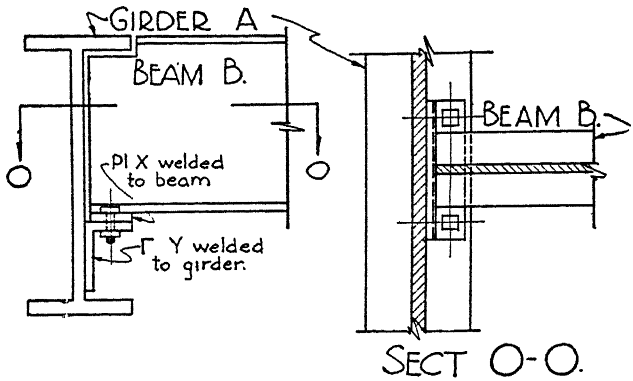


Fig. 807.

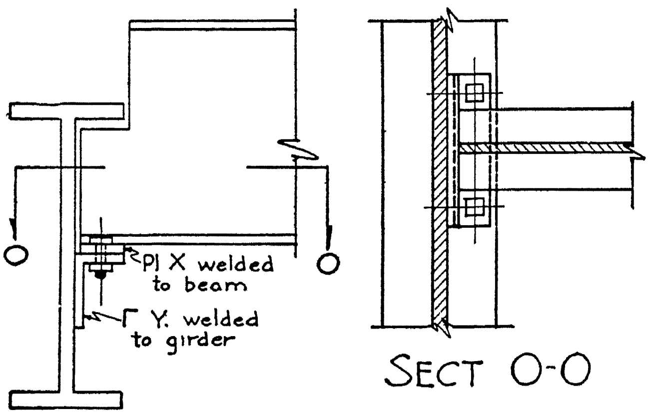


Fig. 808.

Of course, if the beam load is great enough to cause bending of the girder flange, a web-to-web connection should be used.

Fig. 807 shows a beam connection applicable to shallow beams framing to deep girders. The punched plate *X* is shop welded to the bottom flange of beam *B*. The punched seat angle *Y* is shop welded to the web of girder *A*. They are then temporarily connected by bolts in the field as indicated, prior to welding the permanent connection.

The same type of connection shown in Fig. 807 is adaptable for use where beams are situated at different levels. It is illustrated in Fig. 808. When the beam reactions are heavy enough to warrant it a stiffener angle or plate should be welded beneath the seat angle.

Framing Continuous Beams to Girders — In reinforced concrete construction, not only beams framing to columns but also beams framing to girders or to other beams are considered as continuous members and are designed as such. In steel frame construction, it has been customary to design all such beams as freely supported. To that extent,

steel construction is at a disadvantage. Arc welding provides an inexpensive method of making such steel members continuous. The following examples demonstrate how this is accomplished by arc welded design.

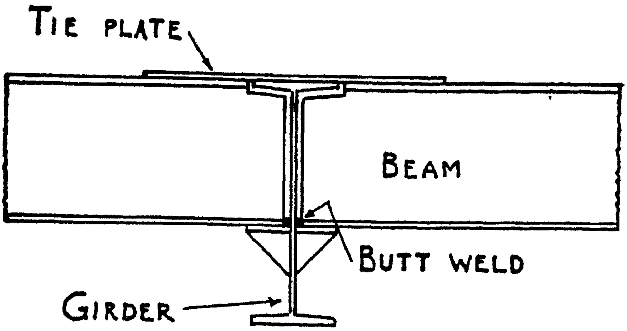


Fig. 809.

Where the girder and supported beams are flush at the top, as shown in Fig. 809, also where the top flanges of the beams are located above the girder top flange, see Fig. 810, the procedure is as follows: The beam is landed on a supporting seat shop-welded to the web of the girder and bolted thereto. Following this operation, another crew butt welds the bottom flange of the beams to the girder web and welds a tie plate to the top flange of the beams on either side of the girder. Since the continuous action of the supported beams depends on the beam opposite and not on any torsion of the girder, it is not necessary to weld the tie plate to the girder.

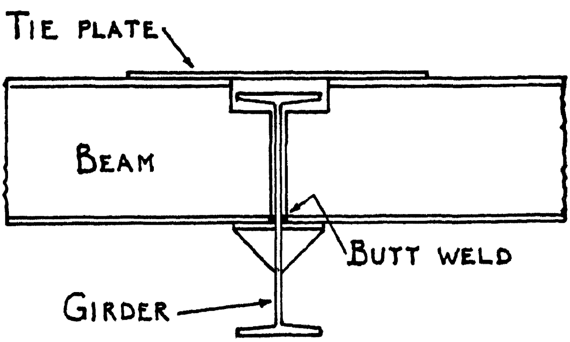


Fig. 810.

Where the top of the supported beams is considerably below that of the girder, as shown in Fig. 811, the tie plate is run through a slot in the girder's web and field welded to the top of the two beams. If the longitudinal shear in the girder is high so that the slot in the web is of consequence, the tie plate is also field welded to the web of the girder.

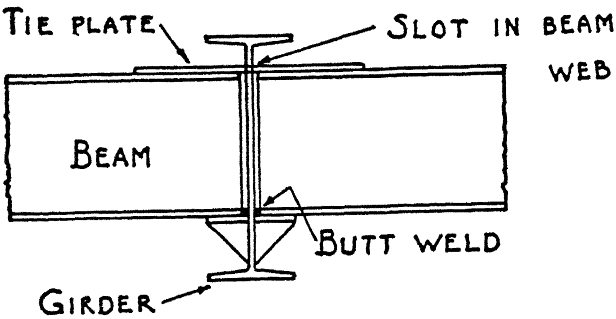


Fig. 811.

For cases where the beams frame just under the girder's top flange, a section of channel cut as shown in Fig. 812 forms a suitable tie plate. This channel is field welded to the top flange of the beams both to transmit the pull across the top of the girder and, in addition, to resist the moment or twist due to the eccentricity of that pull. The example shows continuous 14″ 30-lb. I-beams having a moment value of 63,000 foot pounds. The tension in the channel web across the top of the girder is $\frac{63000}{1'\text{-}3\frac{1}{2}''} = 46000$ lbs. and this web must have a cross section of $\frac{46000}{18000} = 2.65$ square inches (6″-13-lb. channel).

In addition to that direct tension, because the pull of the beam and that of the channel are not in line, the tie channel must be welded to the 14″-beams to resist the moment or twist which tends to lift the channel off the 14″-beam at *a* and to push it down onto the beam at *b*. The shaded triangles show the distribution of the stress induced by the twist. It is maximum tension (upward) at *a*, decreasing to zero, then reverses to compression (downward) increasing to a maximum at *b*. If 9 inches of 3/8″ fillet are used to connect each leg of the 6″ channel to each 14″-beam, the unit stress at *a*, due to the direct pull, is $\frac{41300}{2 \times 9} = 2300$ lbs. This is a horizontal stress.

The moment, due to eccentricity of pull, is $41300 \times 1\frac{1}{2}'' =$ 62000 inch pounds. This moment can be represented by two forces *R*, located 6 inches apart and having a value of $\frac{62000}{6} = 10300$ lbs.

The *average* intensity of the upward force *R* on each of the two 3/8″ welds is $\frac{10300}{2 \times 4\frac{1}{2}} = 1150$ pounds per lineal inch and the intensity at *a* is twice the average or 2300 lbs. This force is upward. Combining this upward force with the horizontal stress at *a*, due to direct pull, we find that the actual total force at *a* is $\sqrt{2300^2 + 2300^2} = 3250$ lbs. slanting upwards to the right. A 3/8″ fillet weld, produced by the shielded arc, has a safe value of 3750 lbs. per lineal inch.

Similarly, at *b*, the direct pull is 2300 lbs. horizontal and the intensity of downward vertical force is also 2300 lbs., resulting in a total force at *b* of 3250 lbs., slanting downwards, to the right.

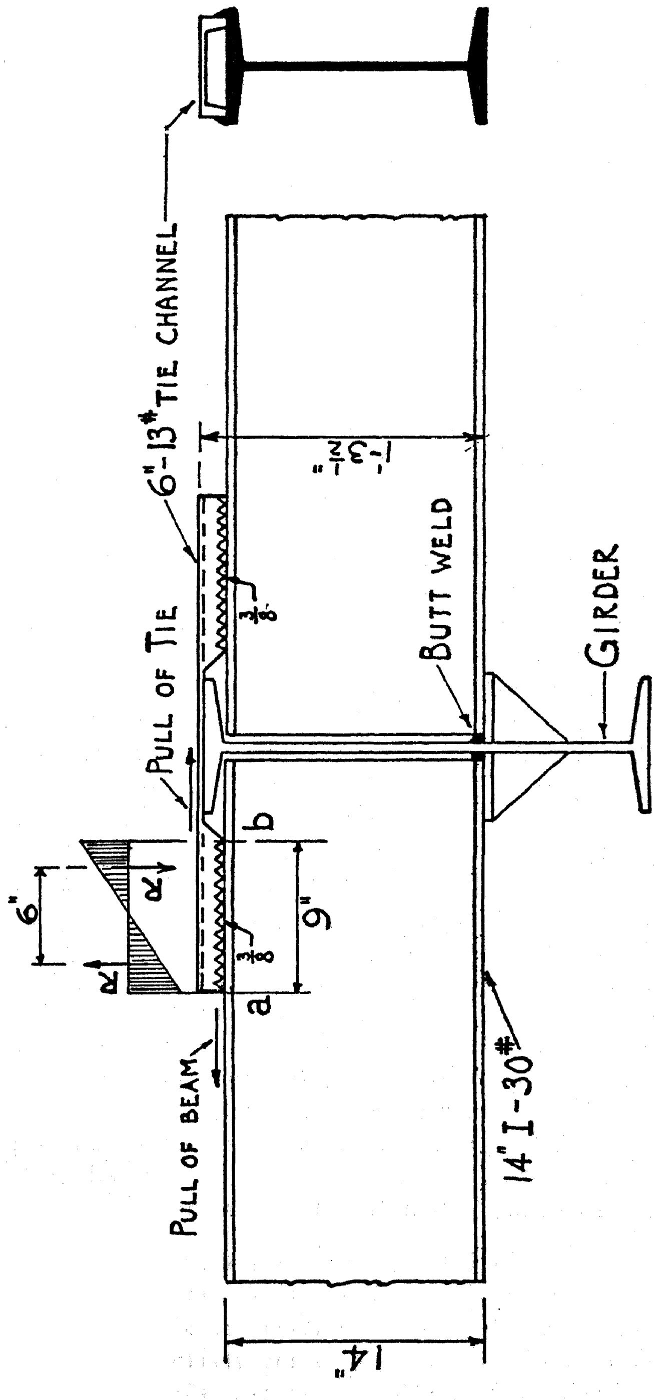

6"-13# TIE CHANNEL
PULL OF TIE
BUTT WELD
GIRDER
PULL OF BEAM
14" I-30#
14"
9"
6"
R
R
a
b
3/8
3/8
1'-3 1/2"

Fig. 812.

Plate Girders. — A plate girder requires extensive shop fabrication because many pieces or members are involved in its construction. It offers, therefore, one of the outstanding examples of the efficiency of arc welded design.

A typical design problem in plate girders is given herewith. The requirements of the problem are as follows:

Girder span, 40 feet.

Load (including allowance for girder weight) 146,000 lbs., concentrated at center of span.

Design of flanges to be made by the standard "Flange Area Method," allowing for web's resistance.

Spacing of stiffeners not to exceed depth of girder.

Bending moment to be resisted, 1,460,000 foot-lbs.

Shear to be resisted 73,000 lbs.

Flange stresses not to exceed 18,000 lbs. per square inch on net section.

The riveted design which meets these requirements is shown in Fig. 813. The arc welded design is shown in Fig. 814. Note that though both girders are of exactly the same size and strength, the arc-welded girder weighs 2,329 lbs. less than the riveted girder, a saving in weight of steel of 22% . The riveted girder requires 890 lbs. more steel in the main members, the web and the flanges, and 1,439 lbs. more steel in the details, the stiffeners, fillers and rivets, than the arc-welded girder. The saving of steel in the web of the arc-welded girder is made possible by use of a 46-inch plate instead of a 48-inch plate; the gross shear is not increased since the indicated continuous welding of flanges to web makes the effective web height the full height of the girder, as in a rolled beam.

The reduction in flange weight is due to there being no holes to be deducted from the gross section and also to the moment arm being a little longer in the welded than in the riveted girder.

The saving of weight in the details is due to the elimination of fillers, to the substitution of lighter stiffeners and to the advantage in weight of the weld metal over the rivets.

In the arc-welded girder there are one-half as many pieces to handle in fabricating as are required for the riveted girder. Thus arc welding also effects a material saving in labor.

Design of Welded Girders.—The proportions of a built-up girder depend on the loading. The welding of a built-up girder is governed by the shears. Typical examples of the most common cases of girder loading, together with the corresponding reactions, are illustrated in Fig. 815. Example *A*, Fig. 815, represents a 40-foot girder which has

DESIGN FOR RIVETING:

Web, 48″ x $\frac{5}{16}$″. Gross Shear: $\frac{73000}{48 \times \frac{5}{16}} = 4866$ lbs. per sq. in.

Flange Area $= \frac{1{,}460{,}000 \times 12}{18{,}000 \times 45\frac{1}{4}} - \frac{\frac{5}{16} \times 48}{8} = 19.63$ sq. in.

2 Angles 8″ x 6″ x $\frac{13}{16}$″ less 2 holes $= 20.00$ sq. in.

Stiffener spacing by A.I.S.C. formula 43½ in.

Rivet Pitch 4½ in.

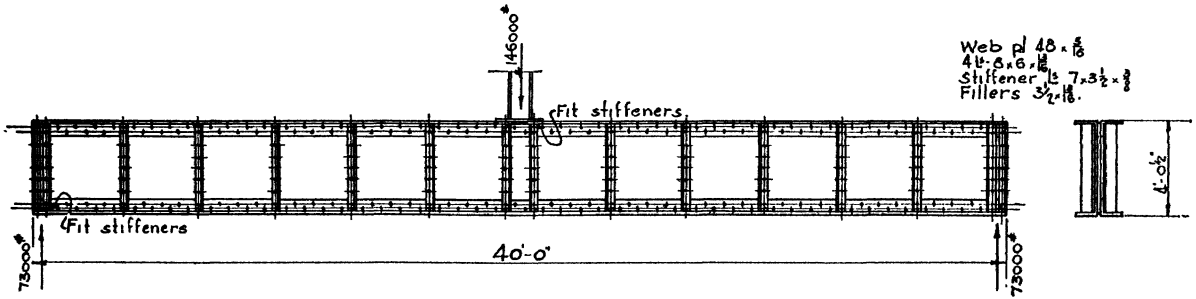


Fig. 813.

RIVETED GIRDER

Girder Weight..................	Web	2040 lbs.
	Flange Angles	5840 lbs.
	32 Stiffener Angles	1614 lbs.
	32 Fillers	904 lbs.
Pieces to assemble: 69.	336 Rivets	219 lbs.
	Total	10617 lbs.

DESIGN FOR ARC WELDING:

Web 46″ x $\frac{5}{16}$″.

Flange Area $= \dfrac{1{,}460{,}000 \times 12}{18{,}000 \times 46\frac{1}{2}} - \dfrac{\frac{5}{16} \times 48\frac{1}{2}}{6} = 18.4$ sq. in.

Plate $18\frac{1}{2}$″ x 1″ (no holes to deduct) $= 18.5$ sq. in.

Stiffener spacing same as for riveting.

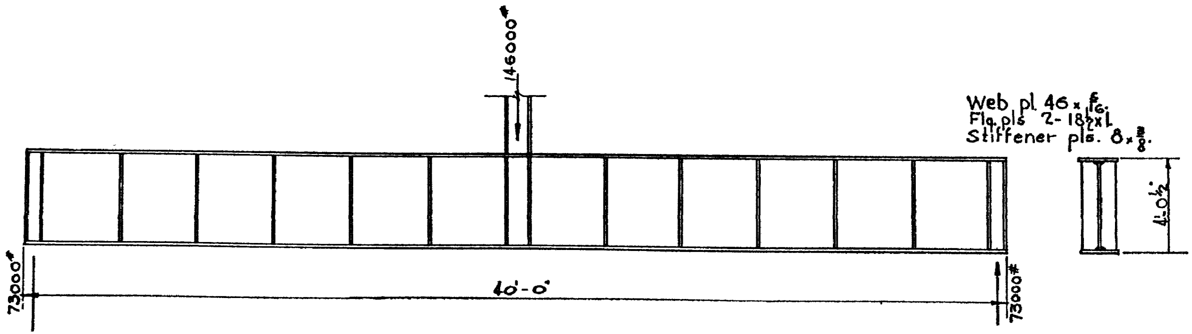


Fig. 814.

WELDED GIRDER

Girder Weight..................	Web	1955 lbs.
	Flange-Plates	5035 lbs.
	32 Stiffener Plates	1238 lbs.
Pieces to assemble: 35.	240 Lin. Ft. $\frac{3}{8}$″ fillet	60 lbs.
	Total	8288 lbs.

to carry a central concentration of 350,000 lbs. together with a uniformly distributed load of 700 lbs. per lineal foot. The resulting moments and shears are shown in Fig. 816. A welded design for this girder is shown in Fig. 817. A discussion of the proportions and welding of this girder follows.

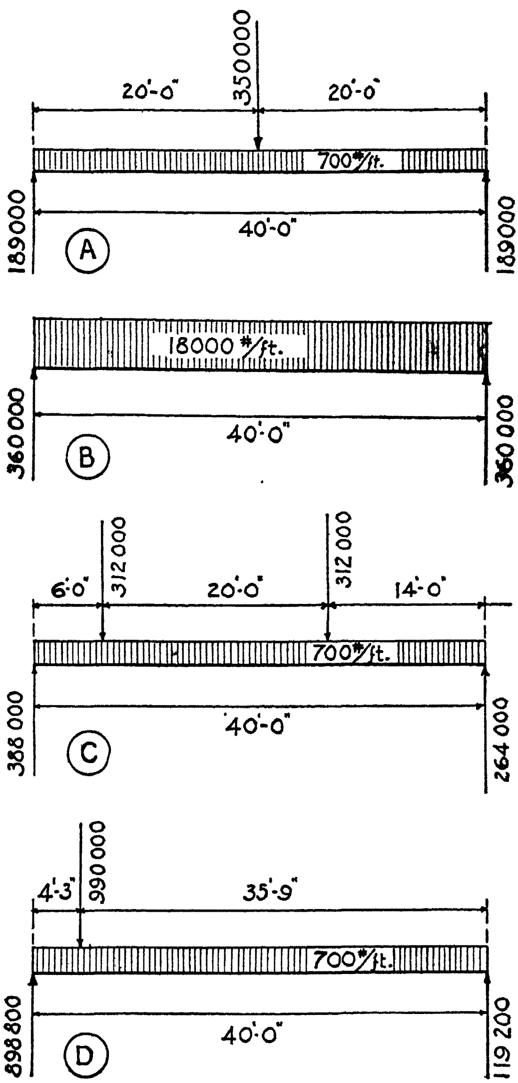


Fig. 815.

Proportions—The maximum shear occurs at the ends of the girder and amounts to 189,000 lbs. A 50″ x 3/8″ web could be used with a stiffener spacing of 28″. A 50″ x 7/16″ web permits a 39″ stiffener spacing, and is chosen for that reason.

The maximum moment is at the center of the girder and amounts to 3,640,000 ft. lbs. A girder made up of a 50″ x 7/16″ web and 18″ x 2½″ flange plates has a moment of inertia of 66,600 and a moment capacity (at 18,000 lbs. per sq. in. maximum stress) of 3,633,000 ft. lbs.

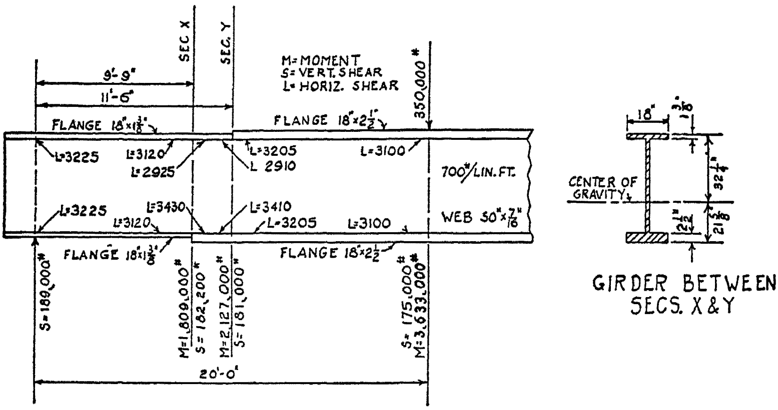


Fig. 816.

At Section X the moment is 1,809,000 ft. lbs. A girder made up of a 50″ x 7/16″ web and 18″ x 1⅜″ flange plates has a moment of inertia of 37,260. Therefore a moment of 1,809,000 ft. lbs. causes a fibre stress of

$$f = \frac{1{,}809{,}000 \times 12 \times 26\frac{3}{8}}{37{,}260} = 15{,}370 \text{ lbs.}$$

This stress comes on the double V-butt weld and is a safe tension stress for shielded arc welding. The bottom flange section is therefore changed at this point to 18″ x 1⅜″.

At Section Y the moment is 2,127,000 ft. lbs. If the top flange is made 18″ x 1⅜″ at this point, as shown in Fig. 816, the bottom flange is 18″ x 2½″, and the web, 50″ x 7/16″. The moment of inertia of this section is 48,660; the center of gravity is 21⅝″ up from the bottom. The maximum fibre stress of the top flange is

$$f = \frac{2{,}127{,}000 \times 12 \times 32\frac{1}{4}}{48{,}660} = 16{,}900 \text{ lbs.}$$

and the maximum fibre stress of the bottom flange is

$$f = \frac{2{,}127{,}000 \times 12 \times 21\frac{5}{8}}{48{,}660} = 11{,}300 \text{ lbs.}$$

The bearing stiffeners over the supporting column, see Fig. 817, are used for the purpose of transmitting 189,000 lbs. from the girder to the column. These stiffeners are in themselves small columns and must be proportioned so they will not buckle. An 8″ x ½″ bracing plate is shown between the end stiffeners; its function is to brace these stiffeners laterally, cutting their effective length to half the height of the web plate. An 8″ x $^{11}/_{16}$″ plate has an area of 5½ sq. in. On an effective height of 25 inches, the stiffness ration is $l/r = 25/.20 = 125$, with a corresponding allowable stress (A.I.S.C.) of 9636 lbs. per sq. in. The combined carrying capacity of the four 8″ x $^{11}/_{16}$″ stiffeners is 4 x 5½ x 9636 = 212,000 lbs.

A similar arrangement of bearing stiffeners is shown in Fig. 817 for a vertical shear of 175,000 lbs. under the center concentration. The function of the intermediate stiffeners is to keep the web vertical, i.e., prevent it from bowing sideways. A thin deep bar is effective for this purpose. The ones shown are 8″ x ⅜″, set out in pairs on either side of the web plate.

The purpose of the welding which connects the web to the flange plates is to resist the sliding tendency that exists at the junction of these two elements. A demonstration of this sliding action or slippage can be made by piling a number of boards of equal length, one on top of another with ends flush, to simulate a beam. After a heavy loading is applied to this "beam" the ends of the boards are no longer flush—the boards having slipped on each other. This is the same kind of slippage which occurs between the web and flanges of a girder when it is heavily loaded.

The intensity of this slippage (horizontal shear) at any vertical section in a girder is found by the formula

$$L = \frac{SAd}{I}, \text{ where}$$

L = the desired sliding tendency intensity (pounds per lineal inch of girder).

S = Vertical shear AT THAT SECTION.

A = Area of flange AT THAT SECTION.

d = distance from the center of gravity of girder (wherever the center of gravity may be) to center of gravity of flange.

I = Moment of inertia AT THAT SECTION.

For instance, the horizontal shear between the top flange and the web over left support is

$$L = \frac{189{,}000 \times (18 \times 1\tfrac{3}{8}) \times 25\tfrac{11}{16}}{37{,}260} = 3{,}225 \text{ lbs.}$$

per lineal inch as noted.

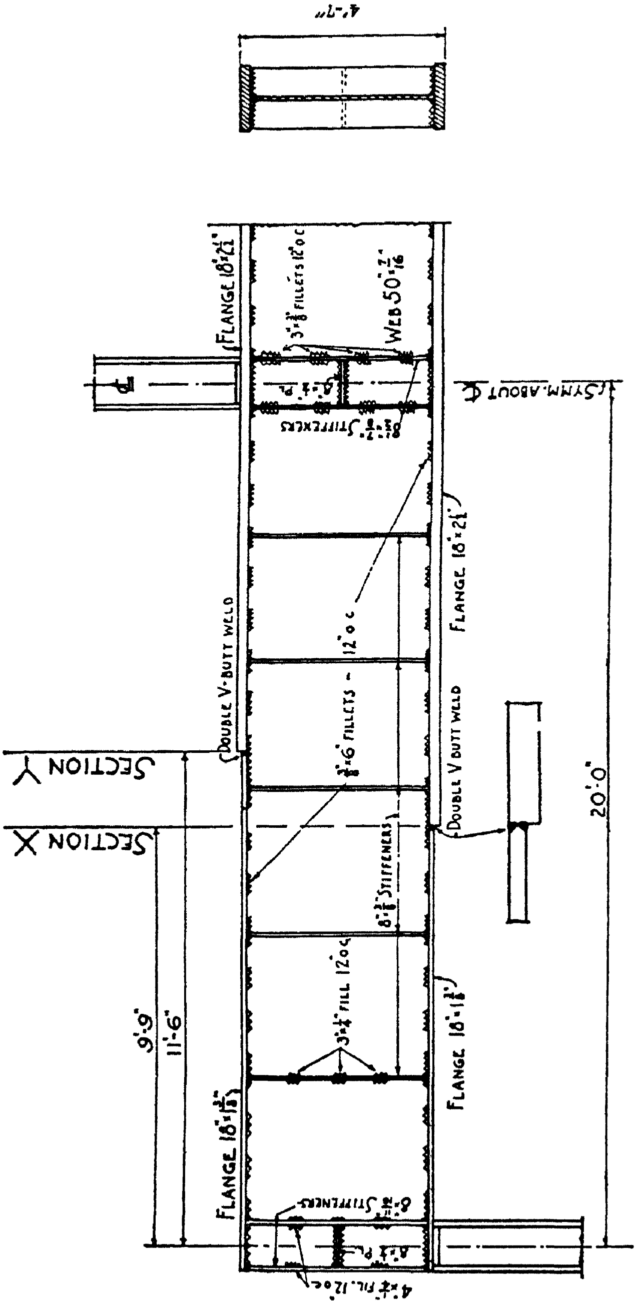


Fig. 817.

Just to the right of Section X the top flange horizontal shear is

$$L = \frac{182{,}200 \times (18 \times 1\tfrac{3}{8}) \times 31\ \tfrac{9}{16}}{48{,}660} = 2{,}925 \text{ lbs.}$$

per lineal inch as noted, while the bottom flange horizontal shear at the same section is

$$L = \frac{182{,}200 \times (18 \times 2\tfrac{1}{2}) \times 20\tfrac{3}{8}}{48{,}660} = 3{,}430 \text{ lbs.}$$

per lineal inch as noted.

An examination of Fig. 816 will show that the horizontal shear is quite uniform from one end of this girder to the other. Therefore, if an arrangement of welding is devised that will resist 3400 lbs. per lineal inch for 480 lineal inches or a total of 1,630,000 lbs. for the length of the girder, there will be no sliding between web and flanges.

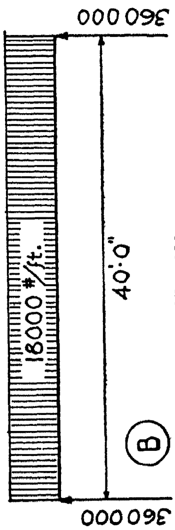


Fig. 818.

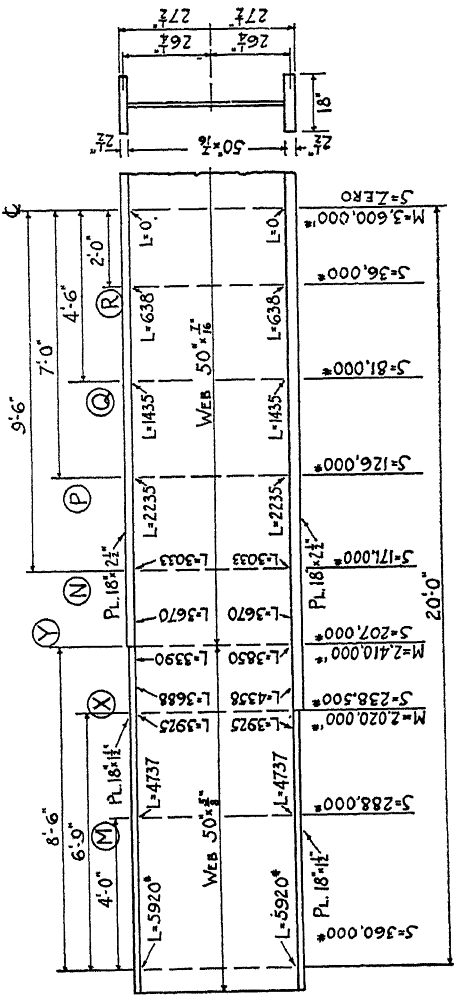


Fig. 819.

A $\frac{3}{8}''$ shielded arc fillet has a value of 3750 lbs. per inch. Two such fillets, 6 inches long on 12 inch centers have a value of $\frac{7500 \times 480}{2} = 1{,}800{,}000$ lbs. This is the welding specified, see Fig 817, and is ample for this girder. This arrangement of welding is all that should be supplied—more welding is a waste of time and material.

As stated previously, the duty of the bearing stiffeners is to take the end load of the girder out of the web into the supporting column (or to take a concentrated load in to the web, as under the center concentration). Therefore the welds which connect the end stiffeners to the web must be able to take 189,000 lbs. out of the web. Fillet welds $4'' \times \frac{1}{4}''$, 12″ o.c., are specified, aggregating 96 lineal inches with a value of 2500 lbs. per inch or a total capacity of $96 \times 2500 = 240{,}000$ lbs. (The outside of the end stiffeners is butt welded to the end of the web.) A similar arrangement is shown for the bearing stiffener under the 350,000-lb. load. The intermediate stiffeners are tacked to the girder web to insure a tight setup. Both they and the bearing stiffeners are full-welded (see Fig. 817) to the flanges to facilitate the shop welding.

Fig. 818 shows a 40-ft. girder intended to carry a load of 720,000 lbs. distributed, or 18,000 lbs. per lineal foot.

Proportions: The bending moment is maximum at the center and amounts to 3,600,000 ft. lbs. To resist this moment, a section consisting of a $50'' \times \frac{7}{16}''$ web plate and $18'' \times 2\frac{1}{2}''$ flanges is provided. The moment of inertia of this section is 66,600 and its moment capacity is

$$M = \frac{18{,}000 \times 66{,}600}{12 \times 27\frac{1}{2}} = 3{,}633{,}000 \text{ ft. lbs.}$$

At section *X*, Fig. 819, the bending moment due to the loading is

$$M = 360{,}000 \times 6\frac{3}{4} - 18{,}000 \times \frac{(6\frac{3}{4})^2}{2} = 2{,}020{,}000 \text{ ft. lbs.}$$

A section consisting of a $50'' \times \frac{5}{8}''$ web and $18'' \times 1\frac{1}{2}''$ flange plates has a moment of inertia of 42,280. The maximum flange stress is then

$$f = \frac{2{,}020{,}000 \times 12 \times 26\frac{1}{2}}{42{,}280} = 15{,}200 \text{ lbs. per sq. in.}$$

This is also the stress resisted by the butt weld in the bottom flange, a reasonable value for a shielded arc weld in tension.

At section *Y*, the moment is

$$360{,}000 \times 8\frac{1}{2} - 18{,}000 \times \frac{(8\frac{1}{2})^2}{2} = 2{,}410{,}000 \text{ ft. lbs.}$$

If the top flange plate is made 18″ x 1½″ from this point to the end of the girder, the bottom flange plate being here 18″ x 2½″, Fig. 822, the center of gravity of this section is 22.323″ up from the bottom and the moment of inertia of the section is 50,980.
The maximum top chord stress is

$$f_c = \frac{2,410,000 \times 31.677 \times 12}{50,980} = 17,970 \text{ lbs. per sq. in.}$$

taken in compression by the top chord butt weld, and the maximum bottom chord stress is

$$f_t = \frac{2,410,000 \times 22.323 \times 12}{50,980} = 12,664 \text{ lbs. per sq. in.}$$

The function of the end stiffeners is to transmit 360,000 lbs. out of the web into the supporting column. Braced by the cross plates at mid height, the effective length of these stiffeners is 25 inches. As a column, an 8″ x 15/16″ plate 25 inches long has a radius of gyration of 0.27 and a stiffness ratio of 93, corresponding to an allowable A.I.S.C. column stress of 12,158 lbs. per sq. in. The total carrying capacity of the four 8″ x 15/16″ stiffeners is then

$$4\left[\,8 \times \frac{15}{16}\,\right] \times 12,158 = 364,700 \text{ lbs.}$$

The intermediate stiffeners serve to brace the web against lateral flexure and help to bring to the web their share of the 18,000 lbs. per ft. uniform load. Stiffener spacing is found from the A.I.S.C. formula:

$$s = 85t\sqrt{\frac{18,000\,A - V}{V}}$$

where s = spacing of stiffeners
A = Area of web plate cross section
V = vertical shear at the section being considered
t = thickness of web plate

At the ends, V = 360,000 lbs., whence

$$s = 85 \times \frac{5}{8}\sqrt{\frac{18,000 \times (50 \times 5/8) - 360,000}{360,000}} = 40''.$$

At section Y, the shear is 360,000 — 18,000 x 8½ = 207,000 lbs. The web is here made 7/16″ thick so the stiffener spacing becomes

$$s = 85 \times \frac{7}{16}\sqrt{\frac{18,000 \times (50 \times 7/16) - 207,000}{207,000}} = 36''.$$

From the above, it is apparent that the general stiffener spacing for this girder is from 3 ft. to 4 ft., as indicated. The maximum load that may be considered brought into the web by each pair of intermediate stiffeners is therefore about 4 x 18,000 lbs. or 72,000 lbs., an amount readily handled by the arrangement indicated.

As previously mentioned, the purpose of welding the flange plates to the web is to resist the horizontal shear stress that arises between flange and web when the girder is loaded. If properly designed, the welding will be uniform if the slippage tendency is uniform. But if the longitudinal shear varies materially from section to section, so should the welding. Near the ends of the girder, Fig. 819, the shear intensity per lineal inch of girder is

$$L = \frac{360{,}000 \times 27 \times 25\frac{3}{4}}{42{,}280} = 5{,}920 \text{ lbs. per in.}$$

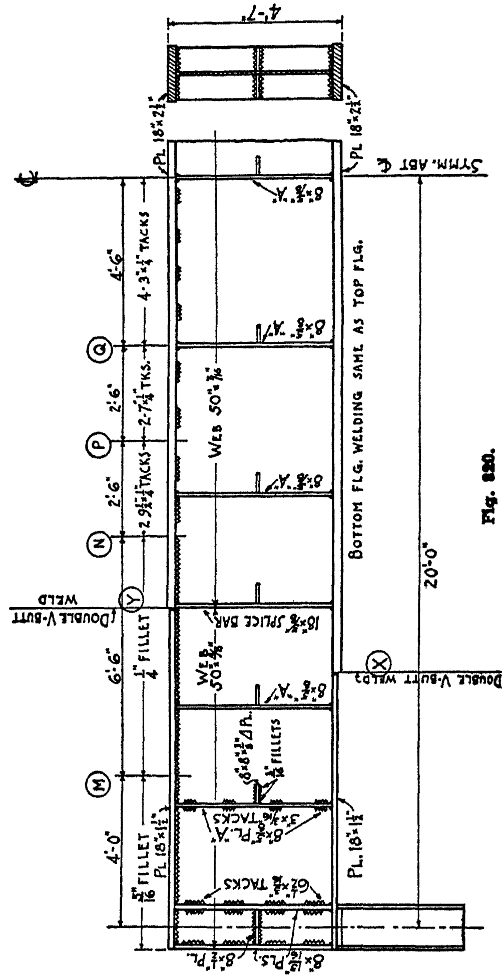


Fig. 820.

To the left of Section X, the vertical shear is 360,000 — 18,000 x 6¾ = 238,500 lbs., whence the longitudinal shear intensity between web and flange plates is

$$L = \frac{238{,}500 \times 27 \times 25\frac{3}{4}}{42{,}280} = 3{,}925 \text{ lbs. per in.}$$

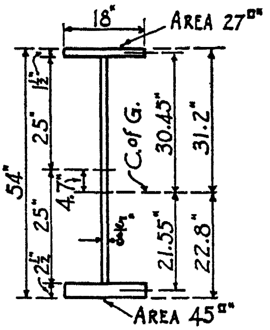
It will be noted that this is much less than six feet away, at the ends of the girder. This difference should be apparent in the welding used.

To the right of section X, the girder section is as shown in Fig. 821. The shear intensity of the top flange plate is

$$L = \frac{238{,}500 \times 27 \times 30.45}{53{,}160} = 3{,}688 \text{ lbs. per in.}$$

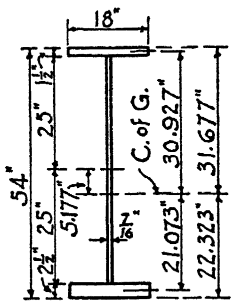
while the shear intensity of the bottom flange plate is

$$L = \frac{238{,}500 \times 45 \times 21.55}{53{,}160} = 4{,}358 \text{ lbs. per in.}$$



GIRDER SECTION TO RIGHT OF SEC'N. X MOM'T. OF INERTIA 53160.

Fig. 821.



EFFECTIVE GIRDER AT SECTION Y MT. OF INERTIA 50980.

Fig. 822.

At section Y, the vertical shear is 360,000 — 18,000 x 8½ = 207,000 lbs. To the left of section Y, the intensity of top flange longitudinal shear (Figs. 819 and 822) is

$$L = \frac{207{,}000 \times 27 \times 30.927}{50{,}980} = 3{,}390 \text{ lbs. per in.}$$

while the intensity of bottom flange longitudinal shear is

$$L = \frac{207{,}000 \times 45 \times 21.073}{50{,}980} = 3{,}850 \text{ lbs. per in.}$$

To the right of section Y, the intensity of longitudinal shear for both flanges (Fig. 819) is

$$L = \frac{207{,}000 \times 45 \times 26\frac{1}{4}}{66{,}600} = 3{,}670 \text{ lbs. per in.}$$

At sections P, Q and R, the longitudinal shears are respectively 2,235, 1,435 and 638 lbs. per lineal inch.

It will be noted that the longitudinal shears—which govern the web-to-flange welding—decrease in this girder from 5,920 lbs. at the ends to 638 lbs. near the center and to zero at the center.

To resist the end longitudinal shear of 5,920 lbs., Fig. 820, a pair of 5/16″ fillets (shielded arc value 6250 lbs. per in.) is employed and continued to section M, four feet from the girder's ends. At this section, the longitudinal shear, Fig. 819, is 4,737 lbs. A pair of 1/4″ fillets (shielded arc value 5,000 lbs.) is now provided and continued for a distance of 6′6″ to section N. Beyond section N, pairs of intermittent 1/4″ fillets are used, the length and spacing varying in propor-

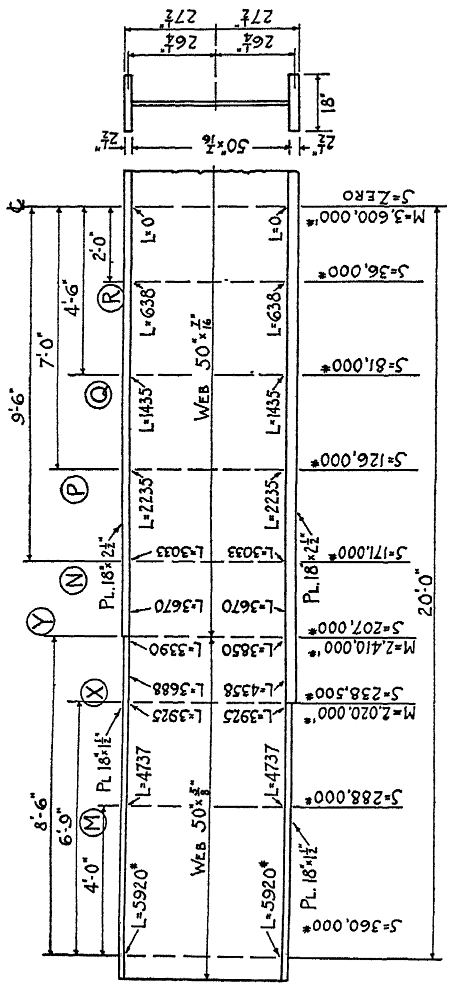


Fig. 823.

tion to the drop in the shear. For instance, between sections P and Q, the slippage may be figured conservatively as 2,235 x 30 = 67,050 lbs. Using two 1/4″ fillets (value 5,000 lbs. per in.), the length of fillet required is $\frac{67{,}050}{5{,}000}$ = 13.4″ or two 7″ x 1/4″ double fillets as shown.

By proportioning the welding to the actual shears, all superfluous expense and time waste are avoided.

The four 8″ x 15/16″ end stiffeners are each required to transmit 90,000 lbs. from girder web to column. The 52 inches of 3/16″ fillet (shielded arc value 1,875 lbs. per in.) connecting each stiffener to the web have a value of 52 x 1,875 = 97,500 lbs. The intermediate stiffeners, carrying a possible load of 36,000 lbs. each require twenty inches of 3/16″ fillet; a total of twenty-four inches is called for in Fig. 820.

The splice bar at section Y together with the transmission of stresses at this section will now be analyzed.

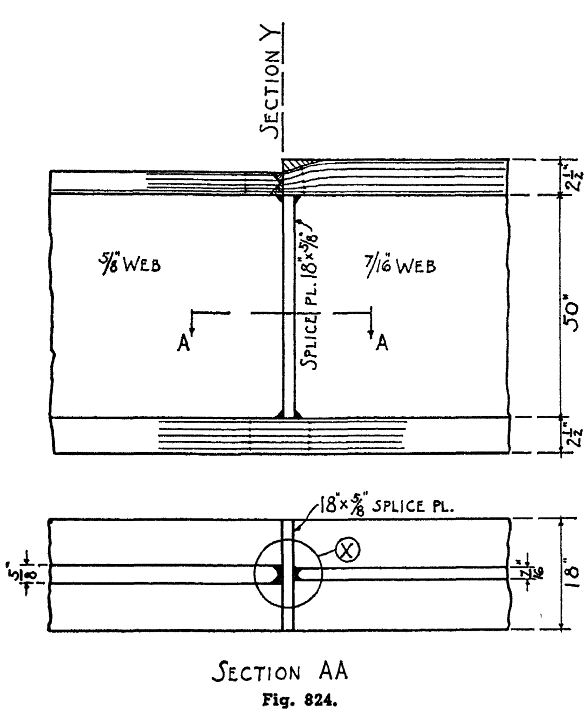


Fig. 824.

At section Y, Fig. 823, both the top flange and the web change section. The bottom flange is continuous through this section; consequently the stream of tension lines carries on uninterruptedly as indicated in Fig. 824. The top flange changes from 18″ x 2½″ to 18″ x 1½″.

The shaded portion of the $2\frac{1}{2}''$ plate is out of action. The compression stress lines in the $2\frac{1}{2}''$ plate converge to meet the stress lines from the $1\frac{1}{2}''$ flange as shown.

The function of the web is a dual one:

(a) It carries its share of the bending moment stresses;

(b) It carries most of the shearing stresses.

At section Y, the web splice must be designed with due regard for both kinds of stresses. At this point, the web thickness changes. A convenient way of splicing the two webs is shown in Fig. 824. It consists of an $18'' \times \frac{5}{8}''$ transverse bar properly welded to the two web plates and to the flanges. This bar also serves as a stiffener plate.

(a) Bending moment stresses in the web: Above the center of gravity, the bending moment stresses in the web plate are horizontal compression forces; below the center of gravity, they are horizontal tension forces. At the center of gravity, the horizontal force is zero. The amount of horizontal force to be resisted at any point by the weld is given by the formula:

$$f = \frac{Myt}{I}$$

where f = the force per inch of girder height;
M = the moment at the section in inch pounds;
y = distance in inches above (or below) center of gravity to point where horizontal force is wanted;
t = web thickness (exclusive of any part not in action);
I = moment of inertia of the entire girder section.

From the above formula, the force per vertical inch at a number of points in section Y is calculated and indicated in Fig. 828a. These tension and compression forces must be resisted by the welds. See Figs. 825 and 826. In Fig. 825, the webs are butt-welded to the $18'' \times \frac{5}{8}''$ bar. The horizontal forces flow directly from one web plate to the other through the welds and through the splice bar.

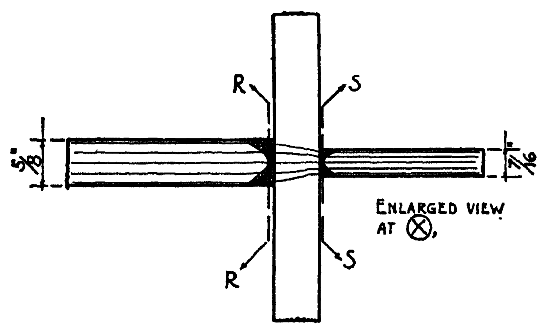


Fig. 825.

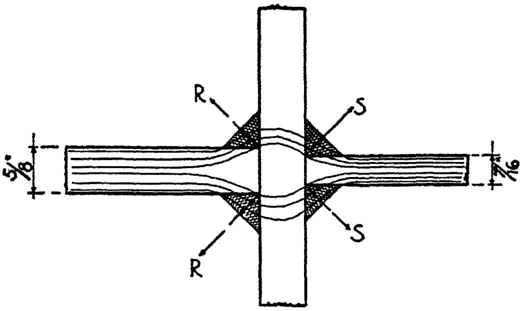


Fig. 828.

At the top of the web, the weld stress on section S-S is $\frac{7475}{7/16} =$ 17,100 lbs. per sq. in. At the same point in the web, the weld stress on section R-R is $\frac{7475}{5/8} =$ 12,000 lbs. per sq. in. At the bottom of the web, the weld stress on section S-S is $\frac{4920}{7/16} = 11{,}250$; on section R-R it is $\frac{4920}{5/8} = 8000$ lbs. per sq. in., and similarly for other points in the web, Fig. 828a. These tension and compression stresses are pulling or pushing horizontally on sections R-R and S-S.

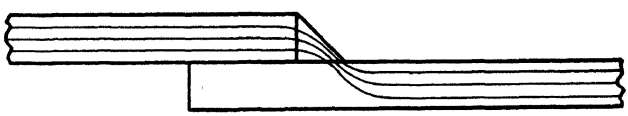
In Fig. 826, the webs are fillet-welded to the splice bar. The horizontal forces are forced to take a curved path through the fillet welds, as indicated. With ½" fillets, the horizontal weld stress per vertical inch at the top of the weld on both sections R-R and S-S is, as usually calculated:

$$\frac{7475}{2 \times \frac{1}{2} \times .707} = 10{,}600 \text{ lbs. per sq. in.}$$

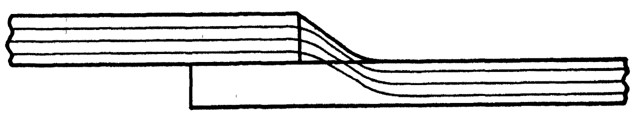
Ten inches above or below the center of gravity, the fillet weld stress is:

$$\frac{2480}{2 \times \frac{1}{2} \times .707} = 3500 \text{ lbs. per sq. in.}$$

By changing the form of the fillets from that illustrated in Fig. 827a, to that shown in Fig. 827b, the flow of stress lines can be considerably improved. (See Page 69.)



a



b

Fig. 827.

(b) Shearing stresses in the web: The vertical shear on section Y is 207,000 lbs. per sq. in., downward on the right of the splice plate and upward on the left. This shear is not uniform from top to the bottom of web plate but increases from the plate's edges to the center of gravity of the girder as shown in Fig. 828b. The amount of vertical shear is found by the same formula as is used to find the amount of horizontal shear at any point, viz.:

$$L = \frac{SAd}{I}, \text{ where}$$

L = the desired shearing intensity (pounds per lineal inch of girder);
S = Vertical shear AT THAT SECTION;
A = Area of flange AT THAT SECTION;
d = distance from the center of gravity of girder (wherever the center of gravity may be) to center of gravity of flange;
I = Moment of inertia AT THAT SECTION;
since the intensity of horizontal shear is equal to the intensity of vertical shear at the same point.

In section S-S, Fig. 825, at the top of the web, the weld stress is

$$\frac{3390}{7/16} = 7750 \text{ lbs. per vertical in. (lbs. per sq. in.)}$$

At the center of gravity, on S-S, the weld stress is

$$\frac{4200}{7/16} = 9600 \text{ lbs. per vertical in. (lbs. per sq. in.)}$$

In section R-R, at the top of the web, the weld stress is $\frac{3390}{5/8} = 5430$ lbs. per sq. in. and at the center of gravity it is $\frac{4200}{5/8} = 6720$ lbs. per sq. in.

In sections R-R and S-S, Fig. 826, at the top of the web, the shearing stress on the ½-in. welds is $\frac{3390}{2 \times 1/2 \times .707} = 4800$ lbs. per sq. in., while

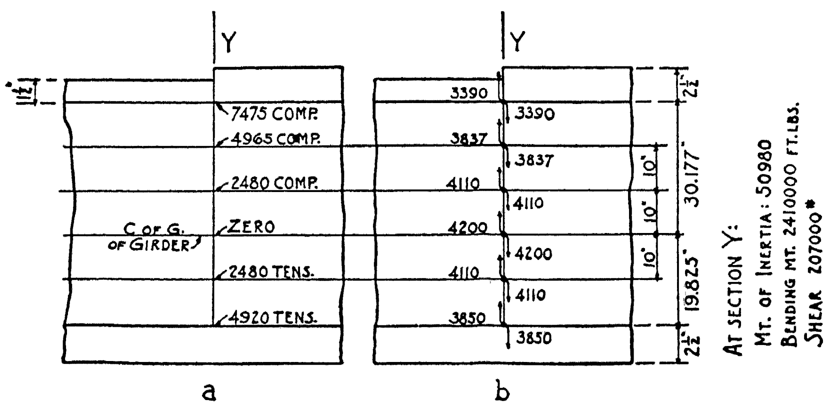


Fig. 828.

at the center of gravity, the stress on the ½-in. welds is $\frac{4200}{2 \times \frac{1}{2} \times .707} =$ 6000 lbs. per sq. in. All of these shearing stresses are slicing vertically on sections *R-R* and *S-S*.

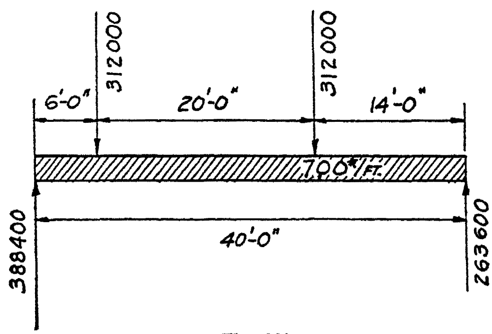


Fig. 829.

Fig. 829 shows a 40 ft. girder supporting two 312,000 lb. concentrated loads and a uniformly distributed load of 700 lbs. per linear foot.

Proportions.—Referring to Fig. 830 the maximum bending moment is found to be 3,621,800 ft. lbs., and is located at the right-hand concentration. A girder having a 50" x 7/16" web and 18" x 2½" flange plates has a moment of inertia of 66,560 and a resisting moment of 3,633,000 ft. lbs. at 18,000 lbs. per sq. in. maximum fibre stress. Therefore this section is used at the point of maximum moment.

The reaction at the right end is 263,600 lbs. On the basis of a shearing allowance of 12,000 lbs. per sq. in., a 50" x 7/16" web has a shear value of 263,000 lbs. and the stiffener spacing is

$$S = 85 \times \tfrac{7}{16} \sqrt{\frac{18000\,(50 \times \tfrac{7}{16}) - 263600}{263600}} = 26''$$

Fig. 830 gives the moments and shears at a number of sections. The shear between the concentrations is relatively low; it increases from 58,200 lbs. to 71,850 lbs. The 7/16" web with stiffeners on about 4 ft. centers is ample for those stresses. At the left concentration, the shear steps up abruptly to 384,200 lbs. and rises slowly to the left reaction where it reaches its maximum value. A 50" x 11/16" web has a shear value of 412,000 lbs. and requires a stiffener spacing of 45". The splice between the two webs is made just to the right of the left concentration where the shear is 71,850 lbs.

Nine feet from the left end, the moment is 2,531,250 ft. lbs.

Nine feet from the right end, the moment is 2,344,000 ft. lbs.

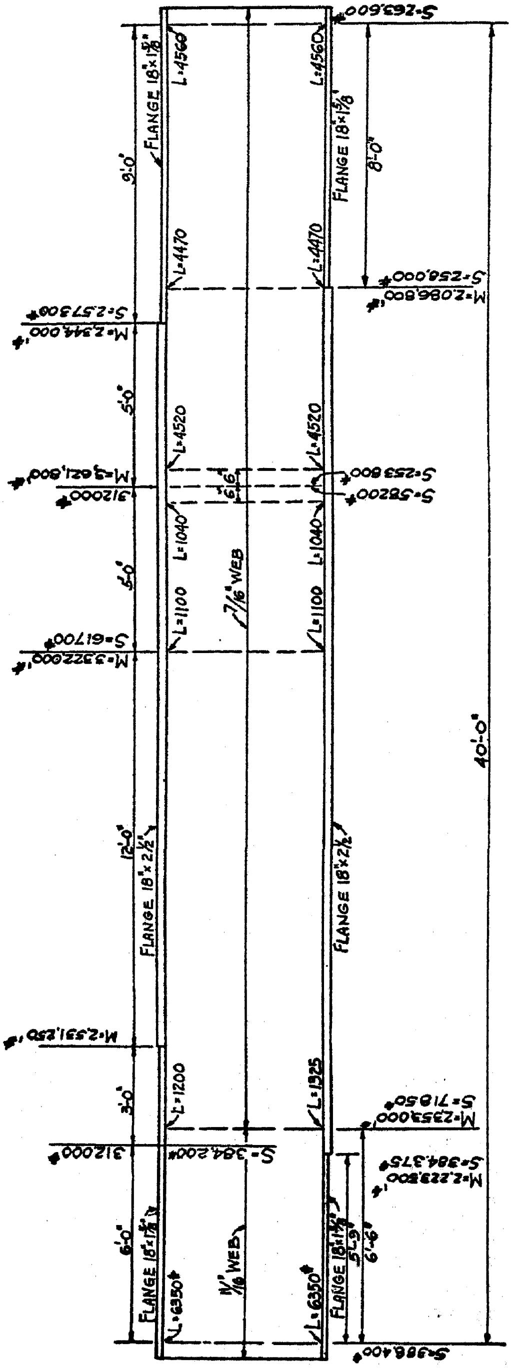


Fig. 830.

If the top flange plates are here made 18″ x 1⅝″, the girder section appears as in Fig. 832. The center of gravity is 23″ from the bottom and the moment of inertia of the section is 53,130. The resisting moment of the girder in compression is

$$M = \frac{18000 \times 53130}{12 \times 31\frac{1}{8}} = 2{,}565{,}000 \text{ ft. lbs.}$$

The maximum stress on the compression butt welds is

$$f = \frac{2{,}531{,}250 \times 12 \times 31\frac{1}{8}}{53130} = 17{,}750 \text{ lbs. per sq. in.}$$

The heavy bottom flange plate is made longer than the top flange in order to restrict the maximum fibre stress on the tension butt welds to 16,250 lbs. per sq. in. or less.

If a girder section made up of 18″ x 1⅝″ top and bottom flange plates and a 50″ x 7/16″ web is chosen, as in Fig. 830, the moment of inertia is 43,600 and the maximum tension will be 15,600 lbs. per sq. in. where the moment is

$$M = \frac{15600 \times 43600}{12 \times 26\frac{5}{8}} = 2{,}125{,}000 \text{ ft. lbs.}$$

Eight feet from the right end, the moment is 2,086,000 ft. lbs. The extreme tension on the butt welds is then

$$f = \frac{2{,}086{,}000 \times 26\frac{5}{8} \times 12}{43600} = 15{,}325 \text{ lbs. per sq. in.}$$

Five feet, nine inches from the left end, the moment is 2,223,500 ft. lbs. Here the web is 50″ x 11/16″; the moment of inertia is 46,160 and the maximum tension on the left end butt welds is

$$f = \frac{2{,}223{,}500 \times 12 \times 26\frac{5}{8}}{46160} = 15{,}400 \text{ lbs. per sq. in.}$$

The left end stiffeners are required to transmit 388,400 lbs. out of the girder web. Braced at mid-height, as shown in Fig. 831, the A.I.S.C. allowable column unit stress for 8″ x 1″ stiffener plate is 12,706 lbs. Hence, the value of the four stiffeners shown is 407,000 lbs.

At the right end, the four 8½″ x ¾″ bars have a value of

$$4\ (8\tfrac{1}{2} \times \tfrac{3}{4})\ 10376 = 264000 \text{ lbs.}$$

Under the 312,000-lb. concentrations, the 8″ x ⅞″ stiffeners distribute the loads to the web. Their value is

$$4\ (8 \times \tfrac{7}{8})\ 11654 = 326000 \text{ lbs.}$$

At the left concentration, the splice plate is made 18″ x ⅞″ so it can act as a stiffener at the same time.

The amount of longitudinal shear, L, between the flanges and the web is indicated at a number of sections in Fig. 830. To the right of the right concentrated load, the longitudinal shear is in the vicinity of 4,500 lbs. per linear inch and this is resisted by two continuous ¼″ fillets with a shielded arc weld value of 5000 lbs. per linear inch.

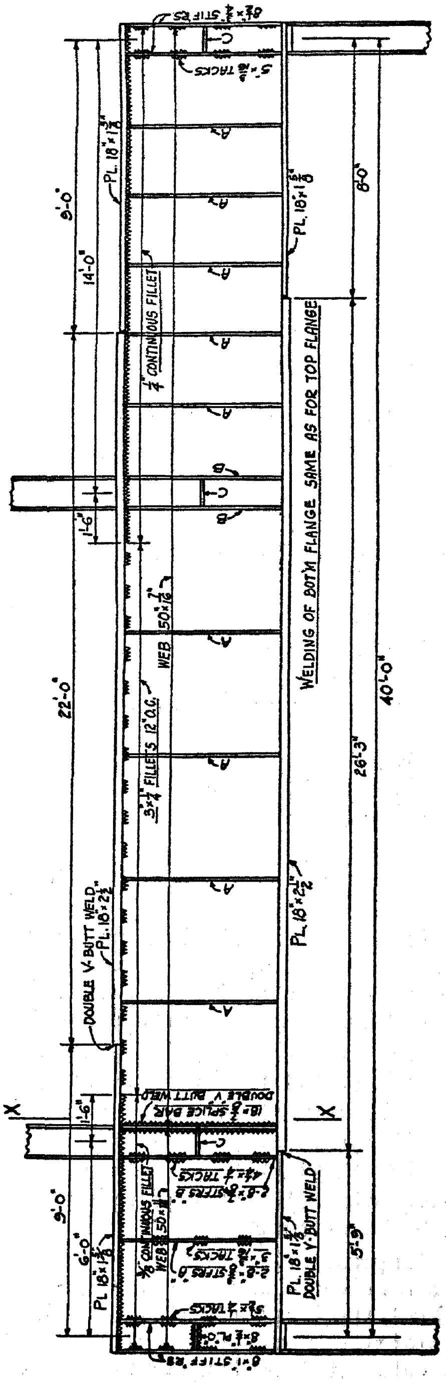

9'-0"
14'-0"
22'-0"
1'-6"
6'-0"
9'-0"
PL. 18"×1 3/4"
PL. 18"×1 5/8"
8'-0"
1/4" CONTINUOUS FILLET
WELDING OF BOT'M FLANGE SAME AS FOR TOP FLANGE
WEB 50"×7/16"
3"×1/4" FILLETS 12" O.C.
DOUBLE V-BUTT WELD
PL. 18"×2 1/2"
PL. 18"×2 1/2"
40'-0"
26'-3"
5'-9"
DOUBLE V BUTT WELD
DOUBLE Y-BUTT WELD
X
X

Fig. 831.

To the left of the left concentration, the longitudinal shear is about 6,300 lbs. per linear inch, resisted by two $3/8''$ continuous fillets with a shielded arc weld value of 7500 lbs. per linear inch.

Between the two concentrations, the longitudinal shear is of low value, ranging from 1000 to 1200 lbs. per inch. Fig. 831 shows $3'' \times 1/4''$ tack welds, 12″ on centers, which is ample with proper welding procedure

Each of the left-end stiffeners is required to transmit 97,000 lbs. to the web. The value of the 44″ of $1/4''$ fillet is $44 \times 2500 = 110{,}000$ lbs.

At the right end, the stiffeners are proportioned for 66,000 lbs. The value of 40″ of $3/16''$ fillet is 75,000 lbs. Under the concentrated loads, each stiffener is required to carry 78,000 lbs. into the web. The 34″ of $1/4''$ fillet welds will handle $34 \times 2500 = 85{,}000$ lbs. The intermediate stiffeners are $8'' \times 3/8''$ bars, tack-welded as shown.

Fig. 832 is a section on line X X, Fig. 831, six and one-half feet from the left end of the girder, alongside the splice plate. At this section, the shear is 71,850 lbs. and the moment is 2,353,000 ft. lbs. The center of gravity is located 23″ from the bottom of the lower flange plate. The moment of inertia is 53,130.

Just under the top flange, the horizontal compression across the splice is

$$f = \frac{2{,}353{,}000 \times 12 \times 29\frac{1}{2} \times \frac{7}{16}}{53130} = 6850 \text{ lbs./sq. in.}$$

This stress diminishes to 4760 lbs./sq. in. at a point $20\frac{1}{2}''$ above the center of gravity and keeps on diminishing until it is zero at the center of gravity, as shown in Fig. 833.

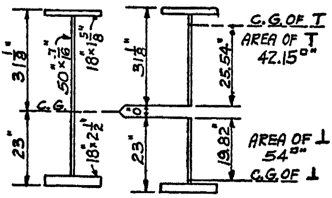


Fig. 832.

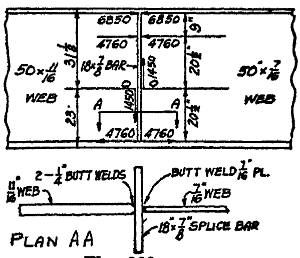


Fig. 833.

Just above the bottom flange, the horizontal tension across the splice is

$$f = \frac{2{,}353{,}000 \times 12 \times 20\frac{1}{2} \times \frac{7}{16}}{53130} = 4760 \text{ lbs./sq. in.}$$

This stress decreases to zero at the center of gravity, Fig. 833.

Referring to Fig. 832, the greatest intensity of vertical shear is opposite the center of gravity and amounts to

$$L = \frac{71850 \times 54 \times 19.82}{53130} = \frac{71850 \times 42.15 \times 25.54}{53130} = 1450 \text{ lbs.}$$

per vertical inch.

This is noted in Fig. 833. The $\frac{7}{16}''$ web plate is butt-welded to the splice bar. This weld has a shielded arc tension value of $\frac{7}{16}$ x 16250 = 7100 lbs. per vertical inch which is well in excess of the maximum horizontal tension just above the bottom flange. The butt weld has a shielded arc compression value of $\frac{7}{16}$ x 18,750 = 8200 lbs. per vertical inch, or 19% in excess of the horizontal compression directly below the top flange.

The stresses in the butt welds that connect the $1\frac{1}{16}''$ web are the same as those in the weld opposite, connecting the $\frac{7}{16}''$ web. Therefore, the welds must be of the same strength on either side of the splice bar. Referring to Fig. 833, the two $\frac{1}{4}''$ corner butt welds connecting the $1\frac{1}{16}''$ web to the splice bar, are fully equal to the butt weld opposite.

The forty foot girder shown in Fig. 834 carries a concentrated load of 990,000 lbs. and a distributed load of 700 lbs. per linear foot.

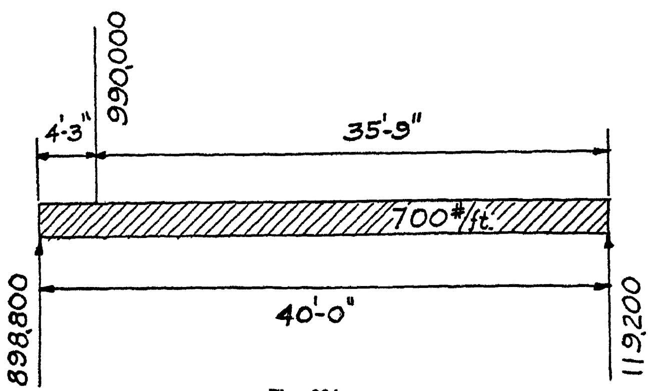


Fig. 834.

Proportions.—On the basis of an allowable shear of 12,000 lbs. per sq. in., the left end reaction requires a 50" x $1\frac{1}{2}''$ web. The shear at the right end, 119,200 lbs., and all the way from the right end to the concentrated load, is comparatively low. A 50" x $\frac{3}{8}''$ web is used as it offers a good relation of height to thickness.

The maximum moment occurs under the concentrated load and amounts to 3,813,600 ft. lbs. A girder comprising a 50" x $1\frac{1}{2}''$ web and 18" x $2\frac{1}{4}''$ flange plates has a moment of inertia of 70,850 and a resisting moment of 3,900,000 ft. lbs. at 18,000 lbs. maximum bending fibre stress. At section "A," the web plates are spliced. The moment here is 3,240,000 ft. lbs. A girder consisting of a 50" x $\frac{3}{8}''$ web and 18" x $2\frac{1}{4}''$ flange plates has a moment of inertia of 59,150 and a resisting moment of 3,250,000 ft. lbs. at 18,000 lbs. maximum fibre stress.

At section "B," Fig. 835, the moment is 2,451,000 ft. lbs. The top flange section here changes to an 18" x $1\frac{5}{8}''$ plate, the bottom flange remaining 18" x $2\frac{1}{4}''$ (See Fig. 836). The center of gravity of this section is $23\frac{3}{4}''$ up from the bottom of the girder; the moment of inertia is 50,000 and the compression resisting moment is 2,495,000 ft. lbs. at 18,000 lbs. maximum fibre stress.

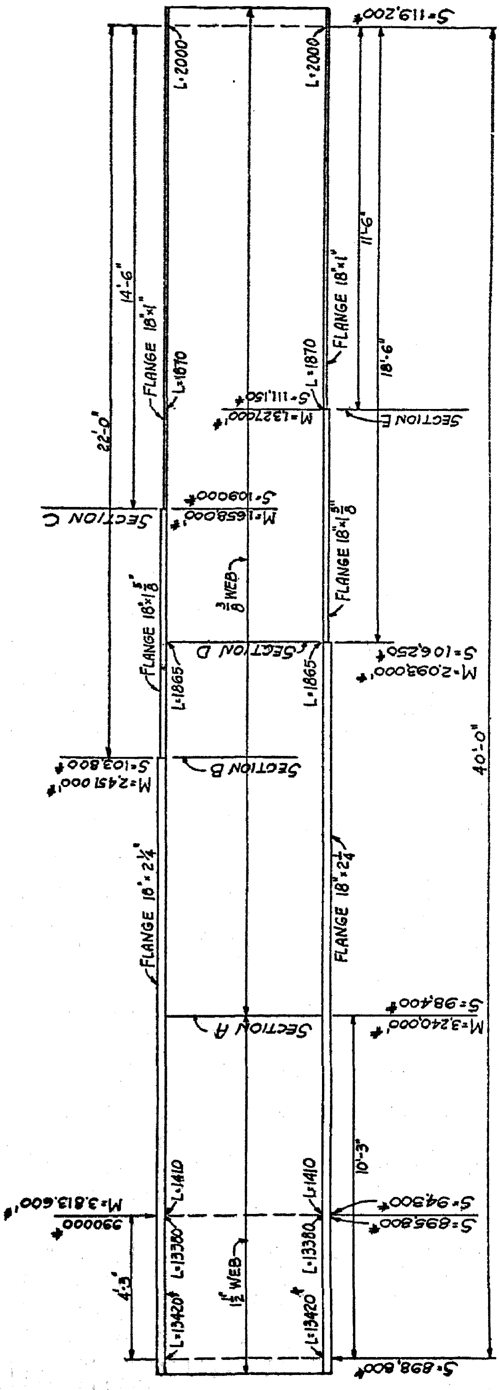

S=119,200#
L=2000
L=2000
FLANGE 18"×1"
L=1870
L=1870
FLANGE 18"×1"
14'-6"
11'-6"
18'-6"
22'-0"
M=1,327,000'#
S=111,150#
SECTION E
SECTION C
M=1,658,000'#
S=109000#
3/8 WEB
FLANGE 18"×1 5/8
FLANGE 18"×1 5/8
SECTION D
S=106,250#
M=2,093,000'#
L=1865
L=1865
M=2,451,000'#
S=103,800#
SECTION B
FLANGE 18"×2 1/4"
FLANGE 18"×2 1/4
40'-0"
SECTION A
S=98,400#
M=3,240,000'#
10'-3"
L=1410
L=1410
M=3,813,600'#
990000#
S=94,300#
S=895,800#
4'-3"
L=13380
L=13380
1 1/2" WEB
L=13420#
L=13420#
S=898,800#

Fig. 835.

At section "C," Fig. 835, the moment is 1,658,000 ft. lbs. The top flange now becomes an 18″ x 1″ plate as shown in Fig. 837, the center of gravity is 22⅛″ up from the bottom; the moment of inertia is 33,800 and the compression resisting moment, at 18,000 lbs. maximum fibre stress, is 1,662,000 ft. lbs.

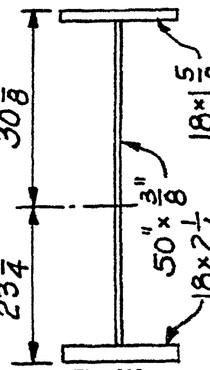


Fig. 836.

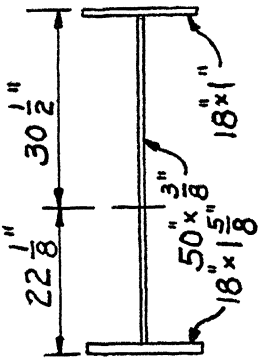


Fig. 837.

At section "D," Fig. 835, the moment is 2,093,000 ft. lbs. The bottom flange is made 18″ x 1⅝″ like the top flange. The moment of inertia of the girder at this section is 43,000. The maximum allowable tension stress on the bottom chord butt welds is 15,600 lbs. per sq. in. For a moment of 2,093,000 ft. lbs.

$$f_t = \frac{2{,}093{,}000 \times 12 \times 26\frac{5}{8}}{43{,}000} = 15{,}560 \text{ lbs. per sq. in.}$$

At section "E," Fig. 835, the moment is 1,327,000 ft. lbs. The bottom flange is now made 18″ x 1″. The moment of inertia of this section is 27,300 and the maximum stress of the bottom chord welds is:

$$f_t = \frac{1{,}327{,}000 \times 12 \times 26}{27{,}300} = 15{,}200 \text{ lbs. per sq. in.}$$

With an unsupported length of 25″ the four 8¼″ x 2″ stiffeners under the concentrated load (Fig. 838), have a stiffness ratio of 43 with a corresponding carrying value of 4 (8¼ x 2) 15,000 = 990,000 lbs. The same stiffeners are used for the left end reaction. At the right hand reaction, 8″ x 11/16″ stiffeners with a stiffness ratio of 125 are used. Their carrying capacity is 212,000 lbs.

For intermediate stiffeners, whose function is to stiffen the web and to square up the girder before the flanges are welded to the web, 8″ x ⅜″ plates are chosen and are connected on as shown in Fig. 838.

Fig. 835 shows the longitudinal shear between the flanges and the web at a number of points. From the right end support to the concentration, this shear varies slightly and is approximately 2000 lbs. per lineal inch for which 6″ x ¼″ fillet welds, 12″ on center, are provided.

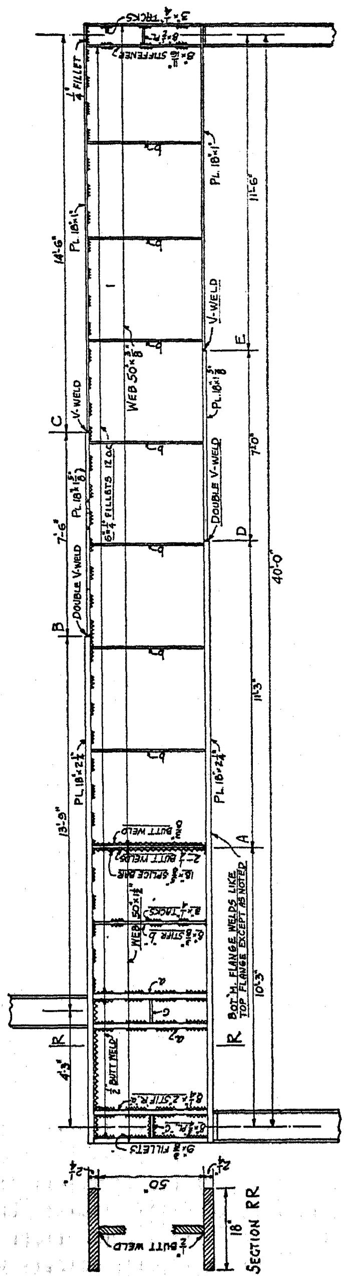


Fig. 838.

From the concentrated load to the left end, the longitudinal shear is about 13,400 lbs. per lineal inch. A shear of this intensity is best handled by butt welds. Fig. 838 shows the top and bottom of the 1½″ web

beveled and connected to the flange plates by two half-inch butt welds having a value of $2 \times 14300 \times \frac{1}{2} = 14{,}300$ lbs. per lineal inch.

The stiffeners under the concentrated load carry 990,000 lbs. into the web. Fig. 838 shows a total of 288 lineal inches of ⅜″ fillet weld which, at 3750 lbs. per inch, have an aggregate value of 1,080,000 lbs. The same welding is used over the left support, the end stiffeners being beveled on the back edge next to the web to receive ⅜″ butt welds.

At the right end, the four stiffeners transmit 119,200 lbs. from the web to the support by means of 3″ x ¼″ tack welds, as shown. This same welding is used for the intermediate stiffeners.

Referring to Fig. 839, the web splice is made at section "A", 10′-3″ from the left end of the girder, where the shear is 98,400 lbs. and the moment is 3,240,000 ft. lbs. At the top of the web, just under the top flange and at the bottom of the web where it joins the bottom flange, the horizontal stress transmitted across the splice is

$$f = \frac{3{,}240{,}000 \times 12 \times 25 \times \frac{3}{8}}{59150} = 6150 \text{ lbs.}$$

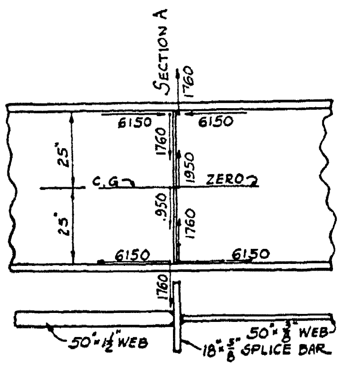


Fig. 839.

The stresses carried by the 1½″ web are the same as those in the ⅜″ plate across the joint. Figs. 838 and 839 show the 1½″ web butt-welded to the splice bar by two ¼″ welds.

As pointed out previously, lines of stress are carried more directly across a splice by butt welds than by fillets; they are therefore preferable to fillets for important connections.

Notes on Design—The top and bottom flange sections of the girders discussed in the previous pages are not changed in the same vertical section because the allowable tension and compression stresses on welds are different. For instance, in Fig. 823, the bottom flange changes from 18 x 1½″ to 18 x 2½″ at section X with a maximum tension weld stress of 15,200 pounds per sq. in. The top flange changes section at section Y with a maximum compression weld stress of 17,970 pounds per sq. in.

A design of this kind gives rise to an unsymmetrical girder section—as between sections X and Y, Fig. 823—one flange being heavier than the other.

At any section, symmetrical or unsymmetrical, the neutral axis of a girder is always located at the center of gravity of that section. In a symmetrical section, the neutral axis is located at the middle of the web since that is the location of the center of gravity of a symmetrical section. In an unsymmetrical section, the neutral axis is located away from the center-line of the web, nearer to the heavier flange because that is the location of the center of gravity of an unsymmetrical section. The shift in the position of the neutral axis is gradual because the position of the true center of gravity of section shifts gradually. By true center of gravity is meant the center of gravity of a section from which has been removed any and all parts (such as hatched portions of Fig. 840) wherein no stress lines flow.

Fig. 840 is an enlarged view of that portion of Fig. 823, between sections X and Y. To the left of section X, the girder is symmetrical and the neutral axis is on the center line of the web, as shown. At section X, the bottom flange increases from 18 x $1\frac{1}{2}''$ to 18 x $2\frac{1}{2}''$; but, as the lines of stress flow in smooth curves, the full effect of the increased plate thickness is not in use until section X_1 has been reached; the shaded part of the 18 x $2\frac{1}{2}''$ flange is not stressed and could be eliminated. At section X_1, the position of the neutral axis is 4.7″ below the center line of the web, at the center of gravity of the unsymmetrical section. Between sections X and X_1 the neutral axis drops gradually as the effect of the greater bottom flange thickness is increasingly felt. Between sections X_1 and Y, the neutral axis keeps on descending due to the gradual change in effective section of the web which is $\frac{5}{8}''$ thick at section X_1 and $\frac{7}{16}''$ at section Y; this is shown by the variation of the moment of inertia which is 53,160 at section X_1 and 50,980 at section Y, the flanges remaining unchanged. The shaded part of the web, section A-A, Fig. 840, carries no stress due to bending.

At section Y, the top flange plate is enlarged; as the full value of this larger plate becomes effective, (at section Y_1) the center of gravity of each successive intermediate section between Y and Y_1 rises and the neutral axis follows, resulting in the curve shown in Fig. 840.

At section X, the longitudinal shear is exactly the same on both sides of the section line, 3,925 pounds, at both top and bottom of the web plate. At section X_1, the values 3688 and 4358 are given in Fig. 823; they are obtained by using the vertical shear found at section X. While this is a customary calculation, the *exact* values of the longitudinal shears are a little less than that, due to the fact that the vertical shear at section X_1, about 10″ farther away from the left support than section X, is somewhat lower than the vertical shear at section X. This statement also applies to section Y_1 as shown in Fig. 840.

The top and bottom flange plates in the girders shown on the previous pages are changed as the stresses warrant. This has been done more for purposes of illustration than from the standpoint of economy. In short girders, it may be better to use a single flange plate without splice as the cost of fitting and welding a number of different plates to form a single flange may overbalance a saving in material.

In Fig. 820, the top flange and the web plate are both spliced in the same vertical plane. In Fig. 831, the web plate and the bottom flange are both spliced directly under the left and concentrated load. Those designs

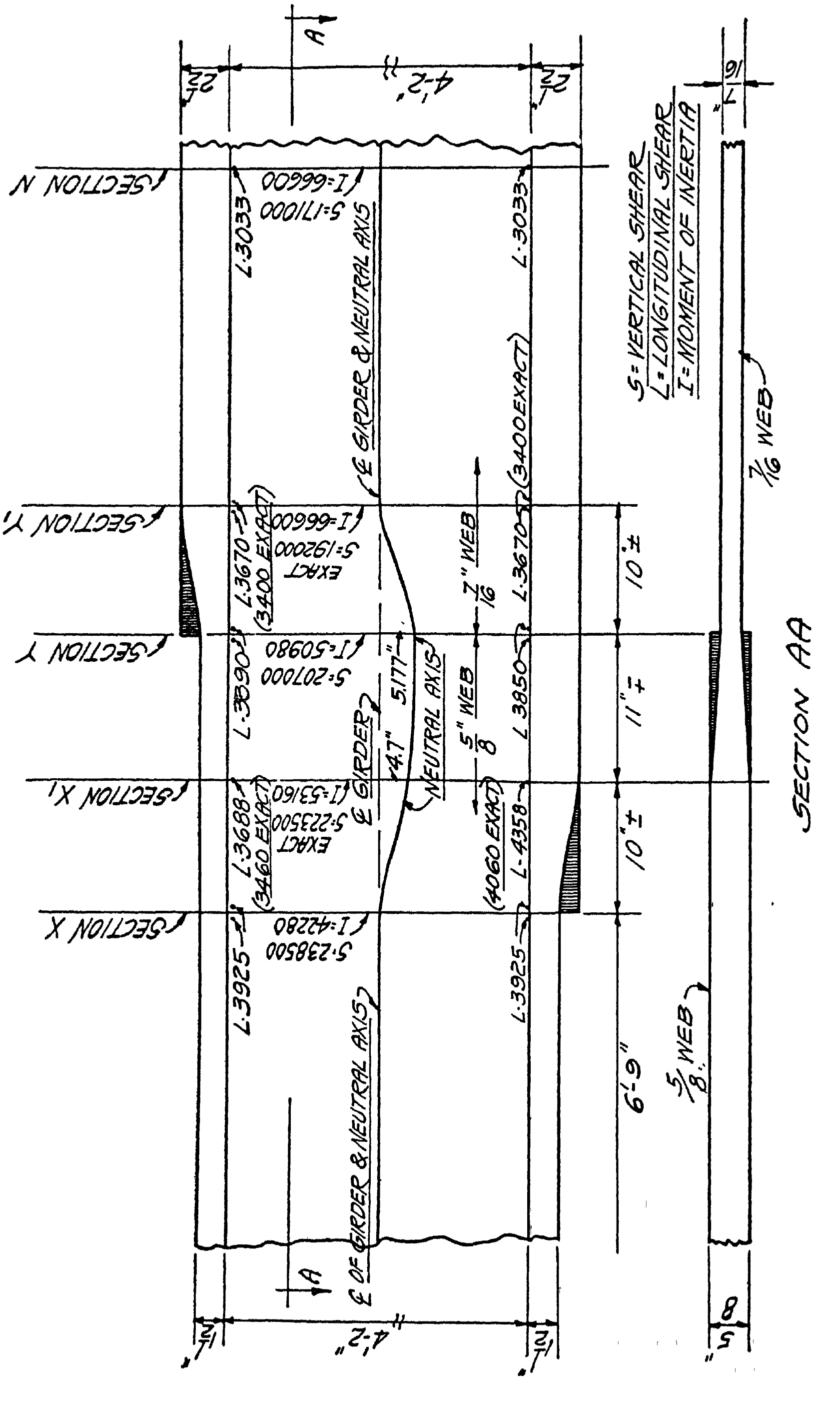

SECTION N
SECTION Y_1
SECTION Y
SECTION X_1
SECTION X
I=66600
S=171000
L-3033
L-3033
℄ GIRDER & NEUTRAL AXIS
I=66600
S=192000
EXACT
L-3670
(3400 EXACT)
L-3670
(3400 EXACT)
I=50980
S=207000
L-3890
L-3850
5.177"
4.7"
℄ GIRDER
NEUTRAL AXIS
7/16" WEB
5/8" WEB
I=53160
S=223500
EXACT
L-3688
(3460 EXACT)
L-4358
(4060 EXACT)
I=42280
S=238500
L-3925
L-3925
℄ OF GIRDER & NEUTRAL AXIS
10"±
11"±
10"±
6'-9"
4'-2"
4'-2"
1 1/2"
1 1/2"
1 1/2"
1 1/2"
A
A
S= VERTICAL SHEAR
L= LONGITUDINAL SHEAR
I= MOMENT OF INERTIA
7/16" WEB
7/16"
5/8" WEB
5/8"
SECTION AA

Fig. 840.

do not agree with the established practice in riveted girders. Some designers are not inclined to consider this good practice in welded work. It should be observed that, in the above designs, all welds are V-butt welds, not fillet welds, so that the component parts are made into a one-piece structure. The two 27″ girder sections shown in Fig. 792 were spliced by a vertical element consisting of a 14″ H column section. At each column face, both flanges and the web of the girder were all spliced in a single vertical plane. Nevertheless, the load that caused buckling of the girder's top flange caused no trouble at the splices even if they were located all in one vertical plane and directly at the point of loading. Furthermore, in Figs. 819 and 830, the web splices are butt-welded whereas, in Fig. 792, the flanges only are butt-welded; the webs are fillet-welded to the splice column.

From the above, it is apparent that the choice of the splice joints in Figs. 819 and 830 will give safe and satisfactory results. The fact that a shielded arc welded girder is a one-piece structure without joints permits placing concentrated loads anywhere on the structure without regard to splice plates.

It is also to be observed that welded girders being one piece structures without joints, the standard design formulae for girders apply more accurately to them than to riveted sections since the formulae are developed for jointless structures and that special considerations have to be made for the effect of rivets and riveting procedure.

Welding Thin Plates to Thick Plates—In the preceding discussions, the fillet welds connecting thin web sections to thick flanges have been designated and calculated as standard 45 degree fillets bearing equally on web and flange. Actually, a good shielded arc fillet connecting a thin plate to a thick one will not be a 45 degree fillet. It will be a 30 degree fillet, which possesses more strength than the other.

Fig. 841 shows a ¼″ vertical plate which is to be welded by ¼″ tacks to a horizontal plate 2″ thick. Because of the great disparity between the thickness of those plates, the amount of welding heat that must be imparted to the thick plate is much greater than that required by the thin

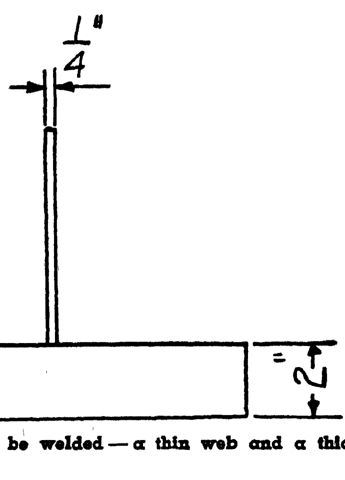


Fig. 841. The plates to be welded—a thin web and a thick flange.

one. If the amount of heat proper for the 2″ plate were imparted equally to both plates, the 1/4″ plate would be burned through because of the excessive heat. On the other hand, if the amount of heat proper for the 1/4″ plate were applied also to the 2″ plate, the weld would not penetrate the latter plate sufficiently for a good weld.

Such unsatisfactory conditions would be brought about if the work were positioned at 45 degrees, as shown in Fig. 842. The weld would be a 1/4″-45 degree fillet; and the heat on both plates being equal, would have produced a poor weld.

If that work is executed with the thin plate set vertically and the thick one horizontally, the electrode is pointed directly at the thick plate as shown in Fig. 843. The weld metal is actually pushed up against the base of the thin plate to a height of 1/4″. This procedure will result in a weld contact 7/16″ wide on the 2″ plate, as shown in Fig. 844, and the slope of the weld will be 30 degrees.

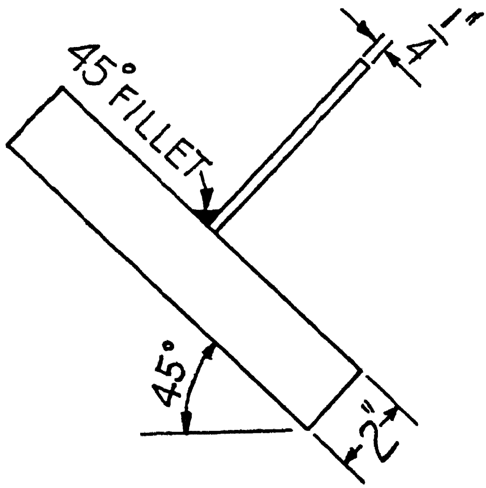


Fig. 842. This position is incorrect for proper penetration in plates of materially different thickness.

The throat section "b", Fig. 845, of such a fillet is 0.217″ long while the throat section "a" of a 1/4″—45 degree fillet is 0.177″ long.

With strength values 25% above those allowed for bare wire by the Fusion Code, the shear value of the 1/4″—45 degree fillet is

125% (11300 x 0.177) = 2500 lbs. per lineal inch

while that of a 1/4″—30 degree fillet is

125% (11300 x 0.217) = 3065 lbs. per lineal inch,

which is 23% greater.

It follows that, if the web plate and flange plates of a girder are of equal thickness, which is a rare condition, the welding of web to flange plates will be most effectively done with the girder web at a 45 degree angle with the floor of the shop.

It is therefore cheaper, from the standpoint of shop positioning, to design girders with relatively thick flange plates and a thin web so that the best welding results will be obtained by setting the web in its normal position, vertical. Another benefit from this set-up is that two welders can work simultaneously on opposite sides of the web thus evening up contraction and avoiding lateral warping of the girder.

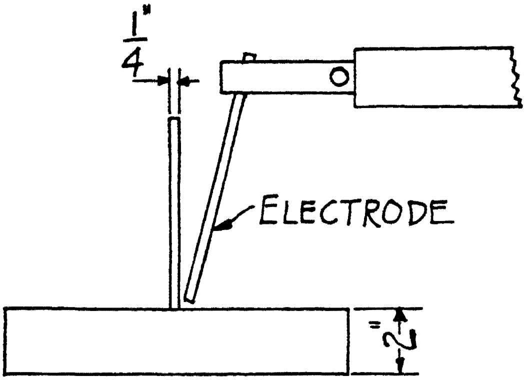


Fig. 843. The correct position. Heat is concentrated on the thick plate.

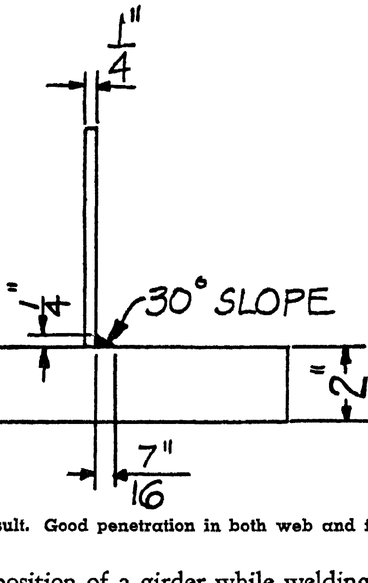


Fig. 844. The result. Good penetration in both web and flange.

The most practical position of a girder while welding stiffeners is to have the web positioned flat, i.e., parallel to the floor of the shop. The stiffeners used solely for web stiffening are generally of about the same thickness as the web and the connection of such stiffeners to the web is made by small tacks. Such welds present no difficulty. The welds that

connect such stiffeners to the flanges are important as their duty is to keep the flanges square with the web while the girder is being welded.

Inasmuch as these welds generally connect a thin stiffener to a thick flange, the disparity of plate thicknesses affects the welding procedure. The welding is now vertical; the electrode, Fig. 846, is pointed at the thick flange and the weld metal pushed over to the thin stiffener while the electrode moves up the joint from the web to the top edge of the stiffener. Thus, a broader bearing of the weld is obtained on the thick flange than

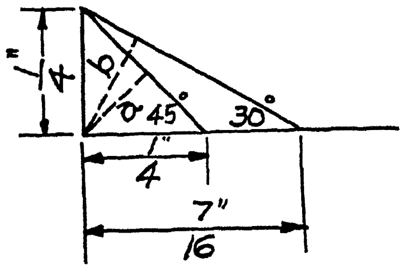


Fig. 845. With a longer throat section, the 30° weld has greater strength.

on the thin stiffener with a corresponding proper distribution of welding heat for good results.

At points of heavy concentrations, the stiffeners are often much thicker than the girder web and compare favorably in thickness with the

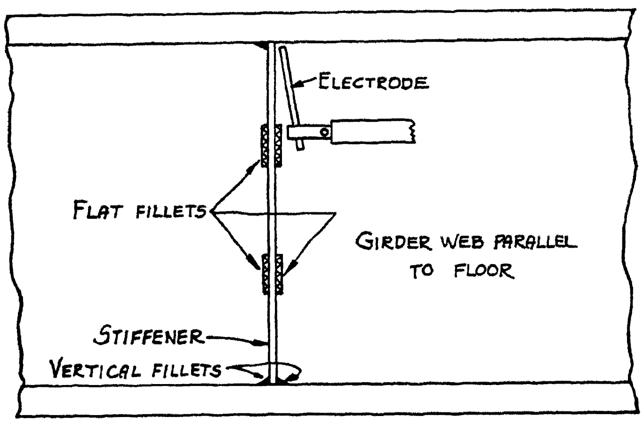


Fig. 846. Position for welding thin web stiffener to thick flanges.

flange plates. Welding such stiffeners to the flange plates is done while the web of the girder is parallel to the shop floor, as in Fig. 846. Since the plates are of substantially the same thickness, the electrode is pointed squarely into the corner formed by flange and stiffener.

The matter of relative heats presents itself again in welding such thick stiffeners to a thin web. Inasmuch as light tacks have been provided between web and stiffeners while the girder web was parallel to the shop floor, the welding called for in the design between web and stiffeners will be done in a vertical position, with the web perpendicular to the floor.

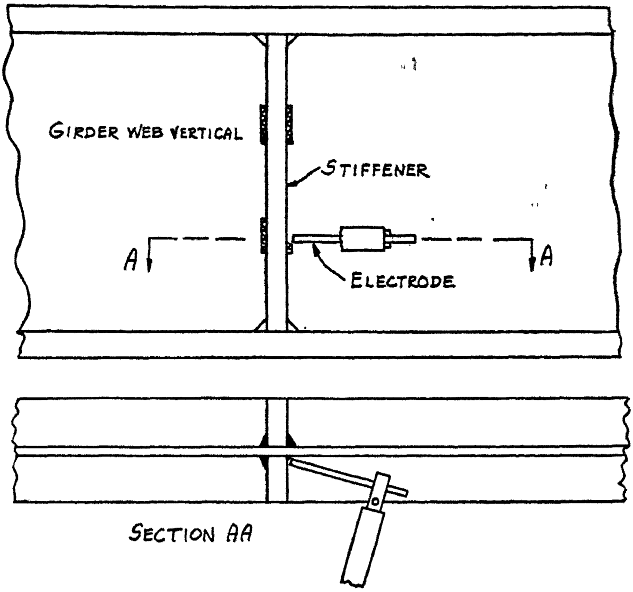


Fig. 847. Position for welding thick stiffener to thin web.

As shown in Fig. 847, the electrode is pointed at the thick stiffener and the molten metal is pushed over, the specified amount, on the web, the heat being concentrated on the thicker element, the stiffener.

The following tests illustrate the strength and reliability of tack welds, connecting thin plates to thick plates, made as described previously.

A specimen consisting of a 3/8″ vertical plate tack welded to a horizontal plate 2″ thick was prepared, as shown in the sketch, Fig. 848.

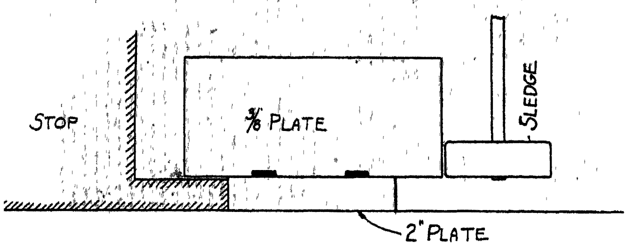


Fig. 848.

There were four tacks, each one a ¼″—30 degree weld 2½″ long, bearing ¼″ on the ⅜″ plate and $\frac{7}{16}$″ on the one 2″ thick.

After the base of the specimen had been butted against a stop, eleven blows of a long-handle 20-pound sledge hammer, wielded with great vigor and dexterity, were delivered to the lower edge of the ⅜″ plate in an endeavor to shear off the tack welds. The end of the ⅜″ plate was deformed by the hammer blows (Fig. 849) but the welds were unaffected.

NOTE DEFORMATION FROM HAMMER BLOWS.

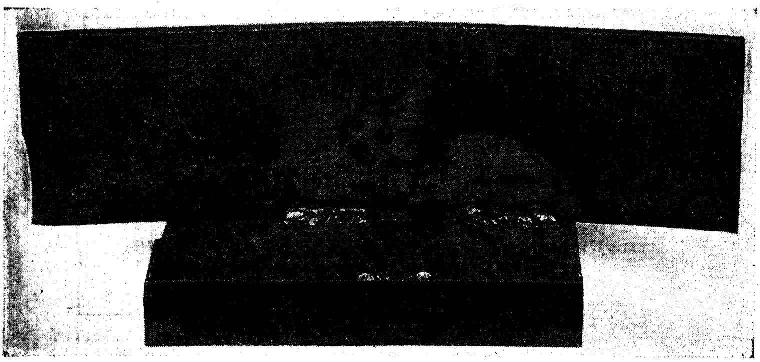


Fig. 849.

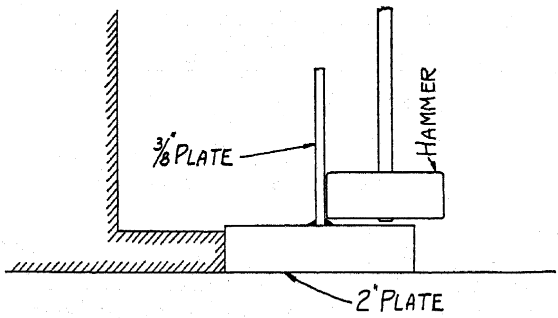


Fig. 850

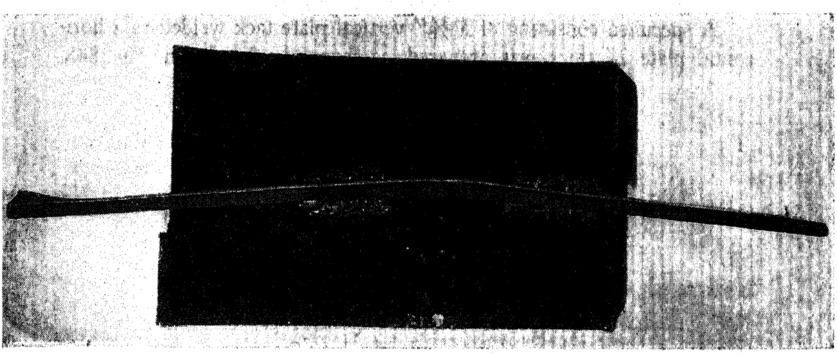


Fig. 851.

The specimen was then turned around 90 degrees and again butted up against the stop, as shown in Fig. 850. The same 20 lb. sledge was brought again into play. This time, eight crashing blows were administered transversely to the $\frac{3}{8}''$ plate in exactly the position shown in Fig. 850, and directly between the tack welds.

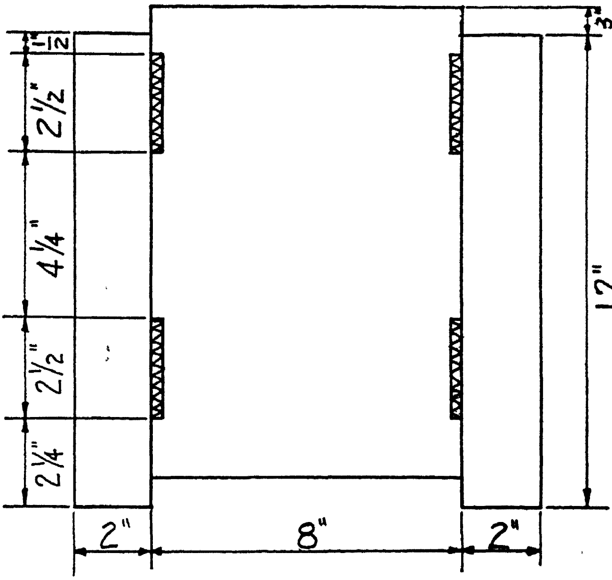


Fig. 852.

Fig. 851 shows that the plate bent, curving even through the welded areas, but the welds were unaffected.

Another specimen, as shown in Fig. 852, was prepared for a quantitative test. It consists of an $8'' \times \frac{1}{4}''$ web 12″ long secured to two $6'' \times 2''$ flanges 12″ long, by eight $\frac{1}{4}''$—30 degree tacks bearing $\frac{1}{4}''$ on the web and $\frac{7}{16}''$ on the flanges.

The specimen was placed in a 300,000 lb. testing machine. At a load of 73,000 lbs. the $\frac{1}{4}''$ web curled over to one side as shown in Fig. 853.

The web plate was then hammered back into its original position. Two $6'' \times \frac{3}{8}''$ plates were plug-welded on to the web and the assembly put back into the testing machine. This time, the beam of the machine dropped at 183,000 pounds.

An examination of Fig. 854 shows the manner of failure: at "A" and "B" the web plate has torn loose from the welds so that daylight may be seen through the separation. The web plate is cracked at points "C" and "D." The vertical movement of the web, slipping away from the bottom of the tacks is clearly visible at points "E," "F," "G," "H."

The specimen was not prepared with any particular care, it being desired to test every day practice. It was welded in nine minutes.

As previously stated, a safe value of 3,065 lbs. per lineal inch was assigned to ¼″—30 degree tacks. The tested specimen had 20 lineal inches of such welding, or an aggregate value of 61,300 lbs., just one-third of the load that caused failure of the web plate.

It was observed that the web had buckled very perceptibly directly over the top of each tack: this is not brought out by the photograph.

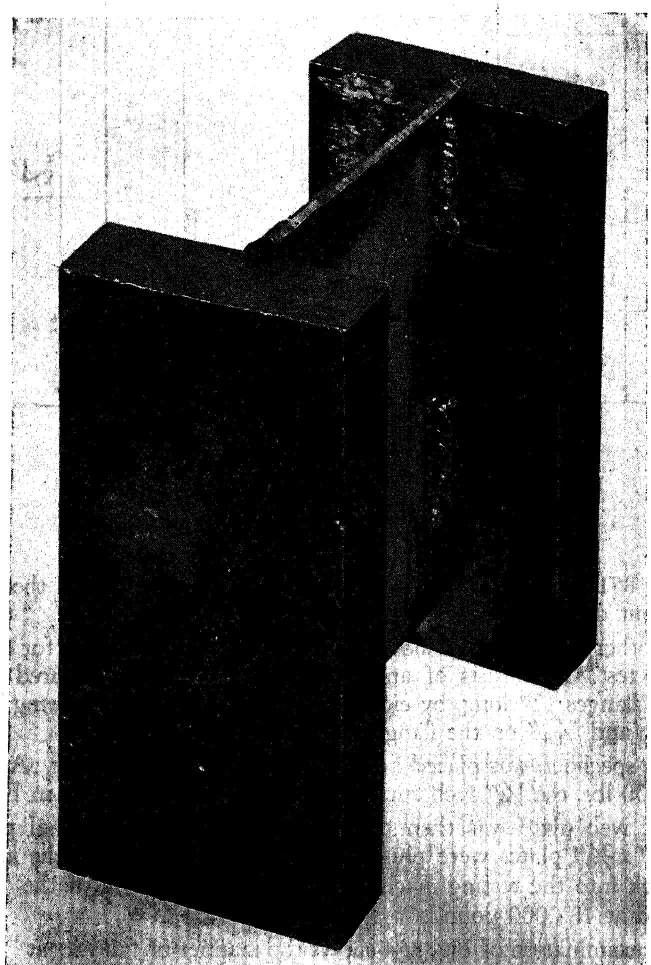


Fig. 853.

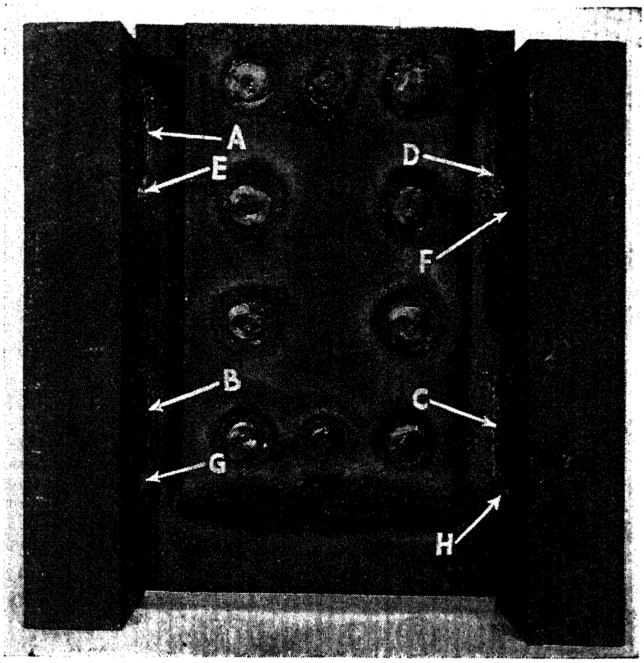


Fig. 854.

Crane Columns and Connections.—In Fig. 855 is illustrated the design for an arc-welded crane column of the usual set-back type, which furnishes a direct seat for the crane girder as well as for the roof trusses, lintels, girts and braces in their respective positions. Close inspection of Fig. 855 and the details, Figs. 856, 857 and 858, will reveal the extreme simplicity of the arc-welded design.

The detail of the set-back shown at A, Fig. 855, is given in Fig. 856. The upper and lower column sections are separated by a plate which forms a cap for the lower section and a base for the upper one. The two sections of the column are shop-welded to this plate and thereby to each other. These welds, as indicated in the drawing, Fig. 856, are adequate to resist the usual bending strains which may be expected at the junction of the two column sections. The same plate forms the seat for the crane girder. Gusset stiffeners support the plate's projection beyond the inner flange of the lower column section and also the inner flange of the upper column section.

Fig. 857 shows the detail at B, Fig. 855. This drawing clearly shows the plate stiffeners arc welded to the column and base plate, also the method of anchorage which utilizes these stiffeners.

Any steel frame must be plumbed and squared before it is fixed in position; therefore, means must positively be provided to permit this to be accomplished. For this reason, Fig. 856 shows bolt holes in the crane girder seat, and Fig. 858 shows bolt holes in the column cap and in the bottom chord lug angle. By means of these holes, the crane girder, Fig.

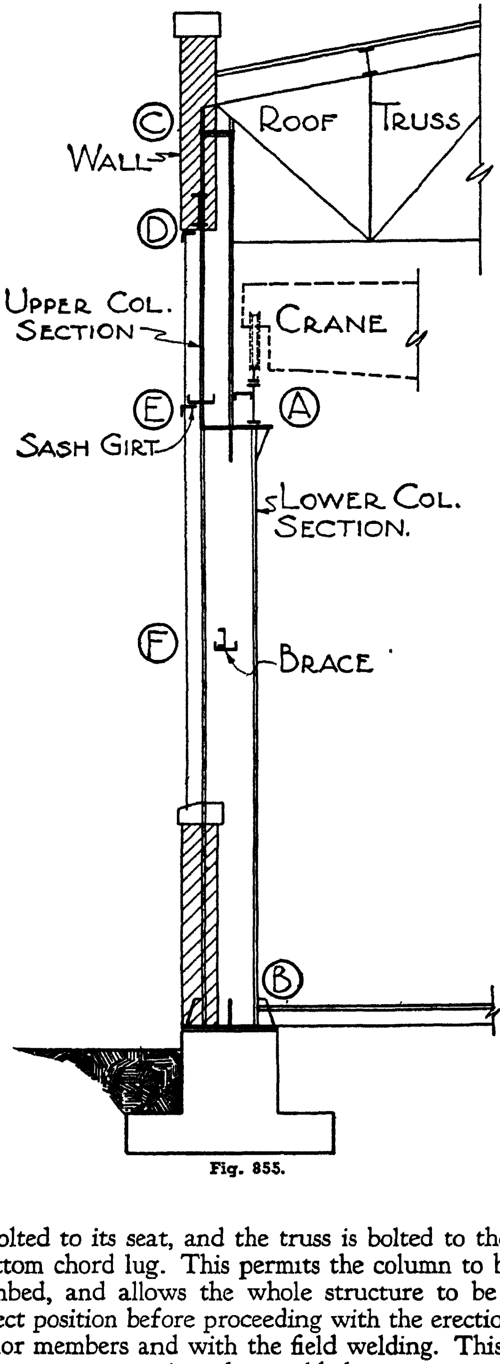


Fig. 855.

856, is field bolted to its seat, and the truss is bolted to the column cap and to the bottom chord lug. This permits the column to be pulled into line and plumbed, and allows the whole structure to be squared and cabled in correct position before proceeding with the erection of the girts and other minor members and with the field welding. This procedure is necessary for any structure, riveted or welded.

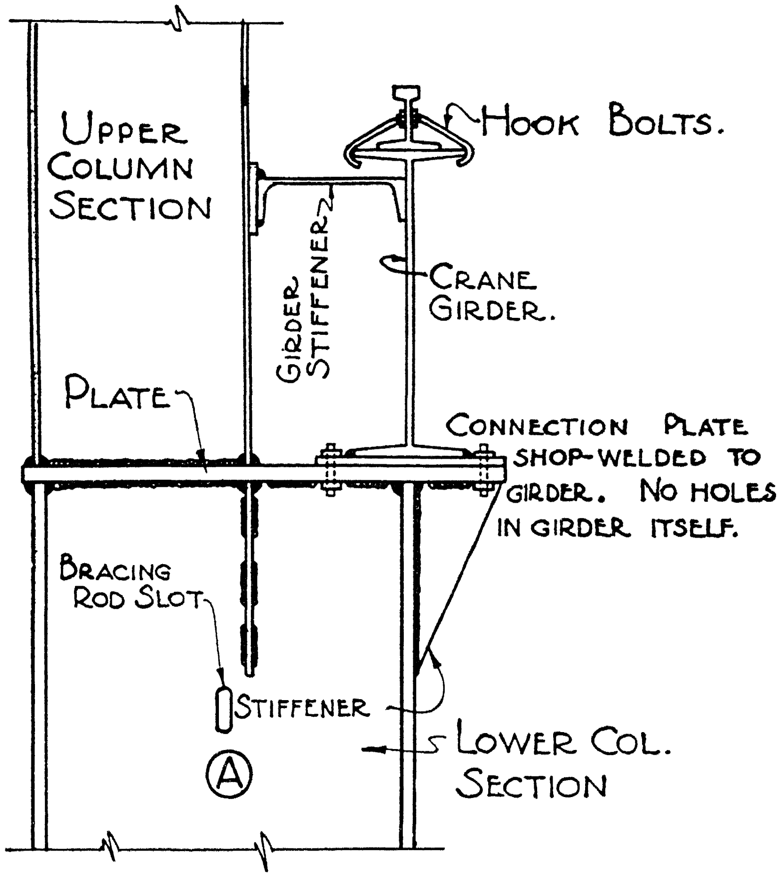


Fig. 856.

A craneway is subjected to considerable vibration from crane operation; therefore, the bolted connections should be supplemented with fillet welds to make those connections rigid.

The crane rails should never be welded to the supporting girders, but hook-bolted thereto in order to allow for adjustment, as required by wear, temperature effects and other causes.

In mill buildings, the principal longitudinal force to be resisted is caused by crane operation. Therefore, generally, some longitudinal bracing between the crane columns is desirable. This may consist of suitable rods, set in slots made with a flame cutter in the crane column webs, or it may consist of tie-angles placed X-fashion between occasional pairs of adjacent columns. These are field-welded to them by means of shop-welded clips attached to the column webs near the girt and strut connections which then become the horizontal members of the bracing systems.

Fig. 859 shows the connection of the lintel beam shown at *D*, Fig. 855, to the crane column. A shop-welded seat angle is provided which locates

the beam vertically. The web of the lintel beam fits right up to the face of the outside flange of the column which locates the beam sideways. The flange-notches locate the lintel beam between the columns.

As soon as the beam is set, it is tack-welded in place, the final welding to the column being done later. Or the seat angle may be made longer than shown and the lintel connected to that seat by two bolts

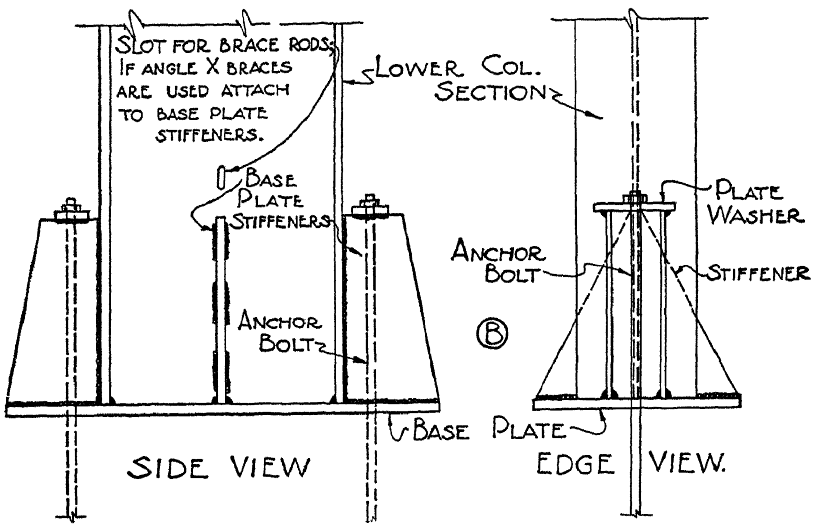


Fig. 857.

and, later, field-welded. The same figure shows the lintel plate and sash angle, both of which are tack-welded at the shop to the bottom flange of the beam.

Fig. 860 shows the connection of the sash girt pictured at *E*, Fig. 855, to the crane column. The girt is composed of a horizontal channel wind stiffener and a sash angle, shop-welded together. The seat angle under the channel locates the girt vertically; the clip at the right of the channel locates it horizontally. The girt must fit between the column webs and is notched to fit around the exterior column flange. By making the channel a little short between the columns, the ends of the channel can be field-welded to the seat angle.

Fig. 861 shows the connection of the column strut shown at *F*, Fig. 855, to the crane column. The strut consists of two channels tack-welded together at the shop. The strut fits between the column webs. It is located vertically by the seat and horizontally by the vertical clip shop-welded to the column.

In designing details for arc-welded connections, care should be taken to locate them so that the members will automatically be erected in exact position. Wherever possible, the field welding should be arranged so that it may be done downward or vertically; welding upward can

be done satisfactorily, but it is slower. The detail drawings should show the assembly of the various members which frame to each other, so that the erectors may understand at a glance the relation

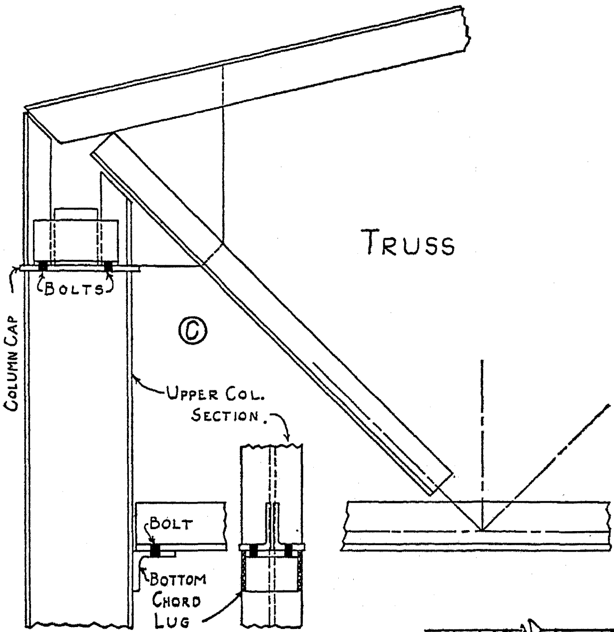


Fig. 858.

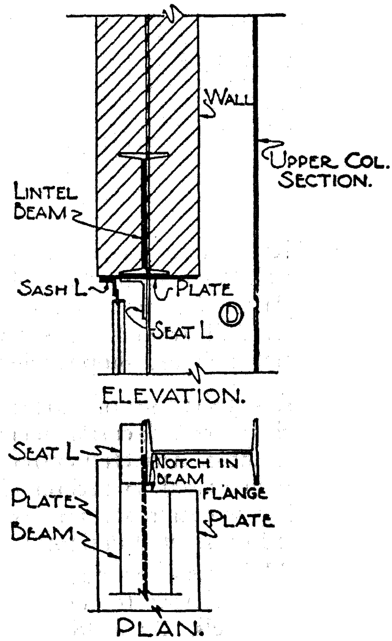


Fig. 859.

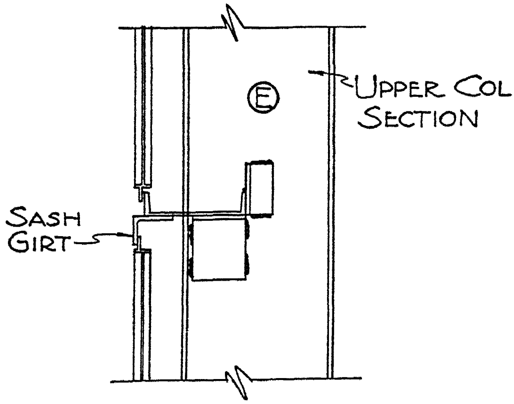


Fig. 860.

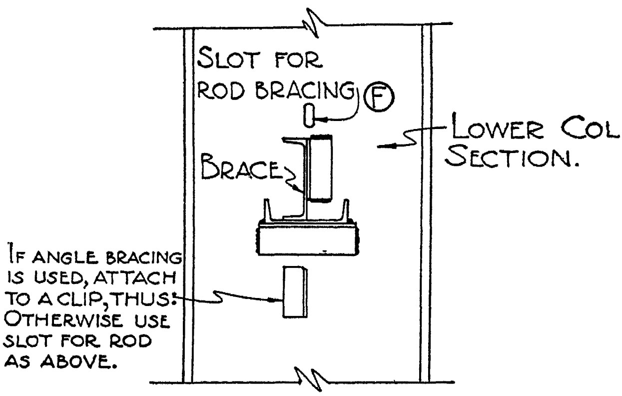


Fig. 861.

of the different members to each other. The details described previously are all designed so that only detail punching, that is, punching of small plates and clips, is required. None of the main members has to be hauled around the shop, the details being all brought to the main members and shop-welded to them.

Trusses. — In trusses of proper arc-welded design gusset plates are generally eliminated. Tension members in the arc-welded design are lighter than those in riveted design because the cross section does not have to be increased to account for rivet holes. These features of arc-welded truss design account for a considerable saving in steel over that required by riveted design.

Arc-welded trusses may be designed in various ways using T-shapes, H-shapes, or U-shapes for chords. The web members are generally angles or channels. Some idea of the efficiency of various types of arc-welded truss design compared to standard riveted design may be

gained by direct comparison of trusses designed to fulfill identical requirements.

The partial plan of a mill building, Fig. 862, shows 32-ft. longitudinal trusses which carry ends of transverse trusses at mid-span. This concentrated load is 32,000 lbs.

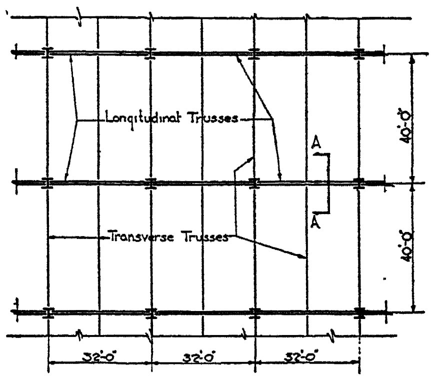


Fig. 862.

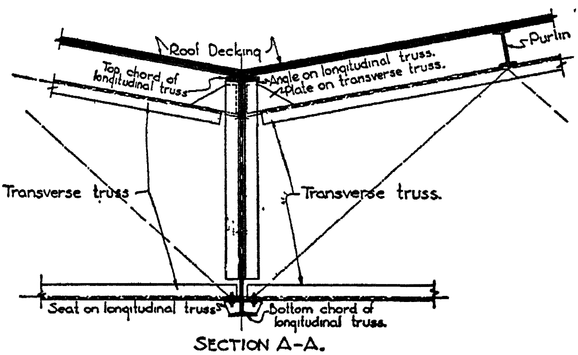


Fig. 863.

From Fig. 863, it will be observed that the longitudinal truss acts also as a purlin because it supports, directly on its top flange a panel of roof decking. The latter load is distributed all along the top chord and amounts to about 300 lbs. per lineal foot. Figs. 864, 865 and 866 show three different designs of arc-welded trusses which fulfill the above requirements. The riveted design is shown in Fig. 867.

It should be noted that the arrangement of web members shown in Fig. 866 brings out a feature peculiar to welded trusses: at any given joint, the component of stress of a web member which is picked up by the *next* web member is transferred directly from one web member to the *next* without passing through the chord at all. This cannot be done in a riveted truss: all web members must be connected to the gusset plates for the full stress that they carry and the component picked up by the *next* web member must pass through the gusset.

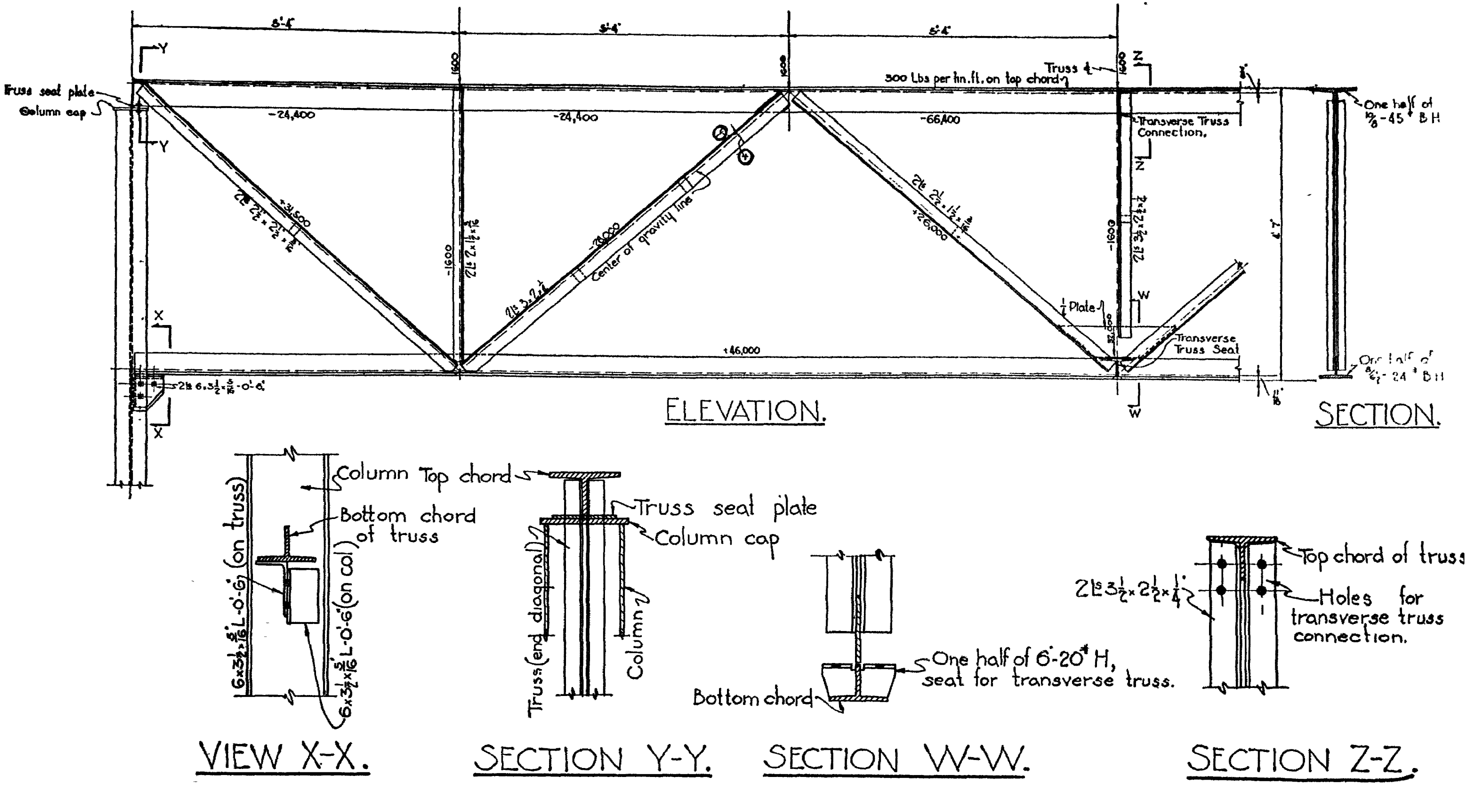

5'-4"
5'-4"
5'-4"
Truss seat plate
Column cap
Truss ℄
300 Lbs per lin. ft. on top chord
-24,400
-24,400
-66,400
-1600
-1600
Transverse Truss Connection.
Center of gravity line
+46,000
½ Plate
Transverse Truss Seat
4'-7"
One half of 10/8-45# B.H.
ELEVATION.
SECTION.
Column
Top chord
Bottom chord of truss
6x3½x5/16 L-0'-6" (on truss)
6x3½x5/16 L-0'-6" (on col)
Truss seat plate
Column cap
Truss (end diagonal)
Column
One half of 6"-20# H, seat for transverse truss.
Bottom chord
2Ls 3½x2½x¼"
Top chord of truss
Holes for transverse truss connection.
VIEW X-X.
SECTION Y-Y.
SECTION W-W.
SECTION Z-Z.

Fig. 840

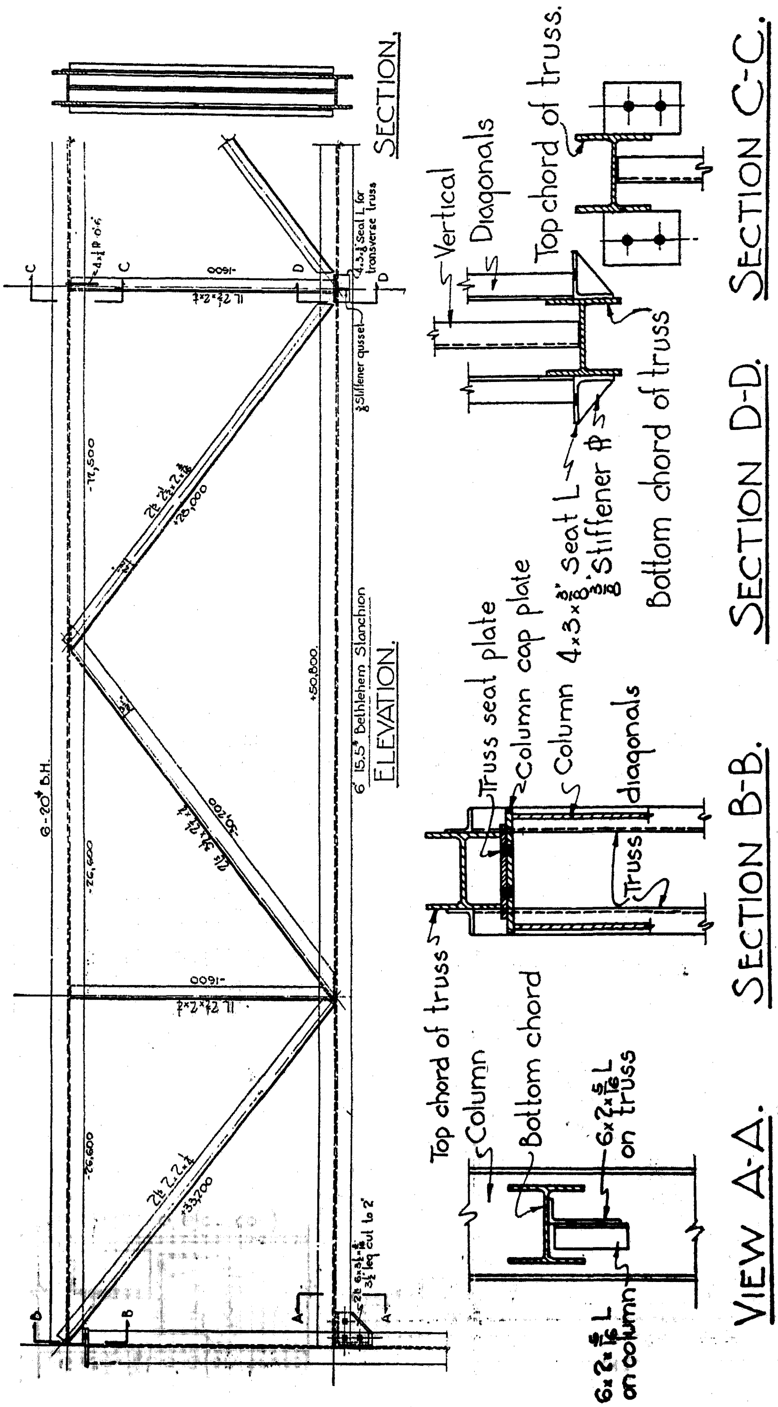
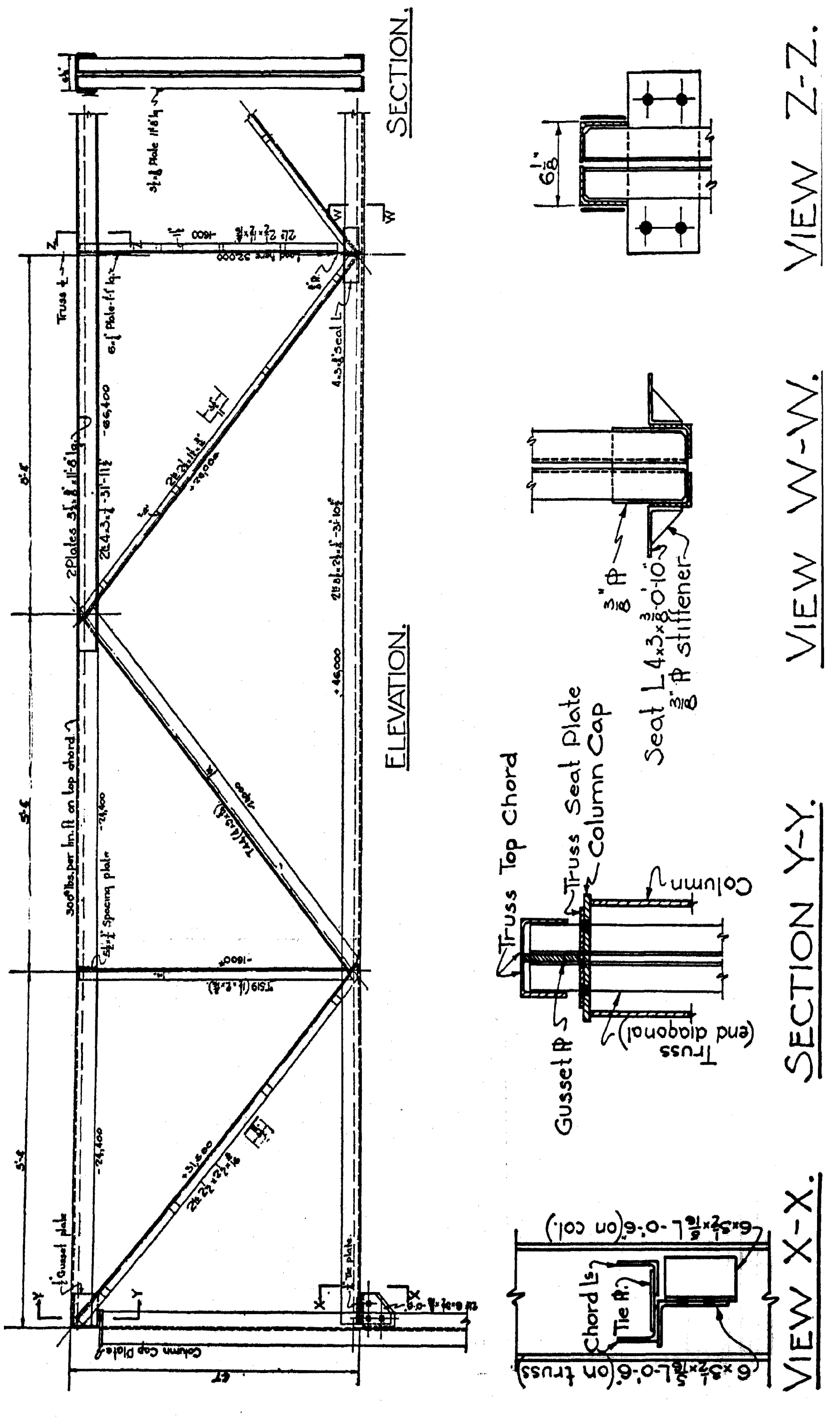

SECTION
ELEVATION
6' 15.5# Bethlehem Stanchion
G-20# B.H.
VIEW A-A.
Top chord of truss
Column
Bottom chord
6x2x5/16 L on truss
6x2x5/16 L on column
SECTION B-B.
Truss seat plate
Column cap plate
Column
diagonals
Truss
SECTION D-D.
Vertical
Diagonals
Seat L
Stiffener
Bottom chord of truss
SECTION C-C.
Top chord of truss.

Fig. 865.


SECTION.
ELEVATION.
VIEW Z-Z.
VIEW W-W.
SECTION Y-Y.
VIEW X-X.
Truss Top Chord
Truss Seat Plate
Column Cap
Column
Gusset Pl
Truss (end diagonal)
Seat L 4x3x3/8-0'-10"
3/8" Pl stiffener
3/8" Pl
Chord Ls
Tie Pl
Column Cap Plate
Gusset plate
Tie plate
Spacing plate

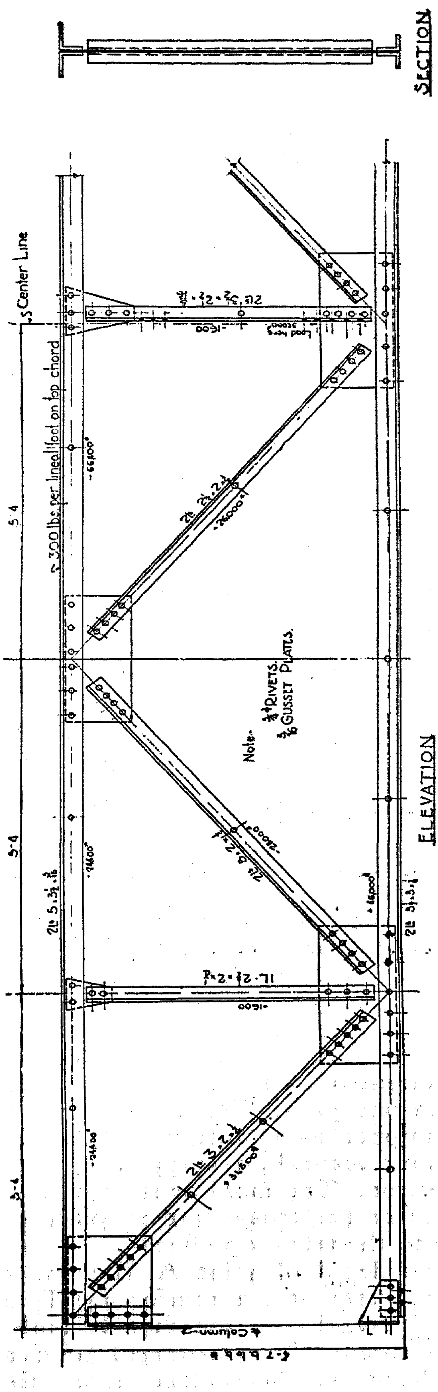


Fig. 867.

The Table A below shows the relative stresses in the chord members of the trusses, the comparative amount of welding required for each welded truss design and the weight of the different trusses. In addition to the direct stress in the bottom chord, the table also gives the maximum stress due to the direct stress and to a load of 500 lbs. hanging from the chord between panel points.

TABLE A

	T-Chord (Fig 864)	H-Chord (Fig. 865)	U-Chord (Fig. 866)	Riveted Truss (Fig 867)
Top chord vertical radius of gyration	1.23	1.49	1.22	1.03
Top chord horizontal radius of gyration	1.97	2.58	2.37	2.37
Allowable compression	11,737	13,700	13,150	13,192
Actual maximum compression, including bending	12,100	13,800	13,280	13,800
Bottom chord stress for given loading	13,850	11,000	16,000	16,000
Bottom chord stress with added 500 lbs. hanger load	17,300	14,500	20,900	20,300
Weight of main members	1,392 lbs.	1,474 lbs.	1,091 lbs.	1,253 lbs.
Weight of details	58 lbs.	51 lbs.	89 lbs.	337 lbs.
Total weight	1,450 lbs.	1,525 lbs.	1,180 lbs.	1,590 lbs.
Lineal feet of welding	32	27	52	

Fig. 868 shows an 80 ft. mill roof truss of standard proportions. Mill trusses usually act as braces for the tops of heavy crane columns. The inherent rigidity of welded construction is a desirable feature in mill structures on account of the lateral forces due to crane operation and to wind that have to be resisted.

The usual corrugated iron roofing requires a steep slope: as a consequence, the center depth of this type of truss is too great to permit shipping the trusses in one piece. Segments AED, having a shipping depth of 7 feet, are shipped as a unit; the bottom chord to the right of joint D and the center vertical are shipped separately and assembled in the field before erection. The monitor is erected either as a number of separate members after the trusses are in place or hoisted up as a single unit and bolted to the truss top chord.

Fig. 869 shows the detail of joint A, the end of the truss. To provide enough shearing strength, a reinforcing T, made of a section of 14 inch beam, is butt-welded in the shop to both the top and bottom chords. This reinforcing T is arranged to clear the roof deck. The end of the T's flange is fillet-welded across the top of the top

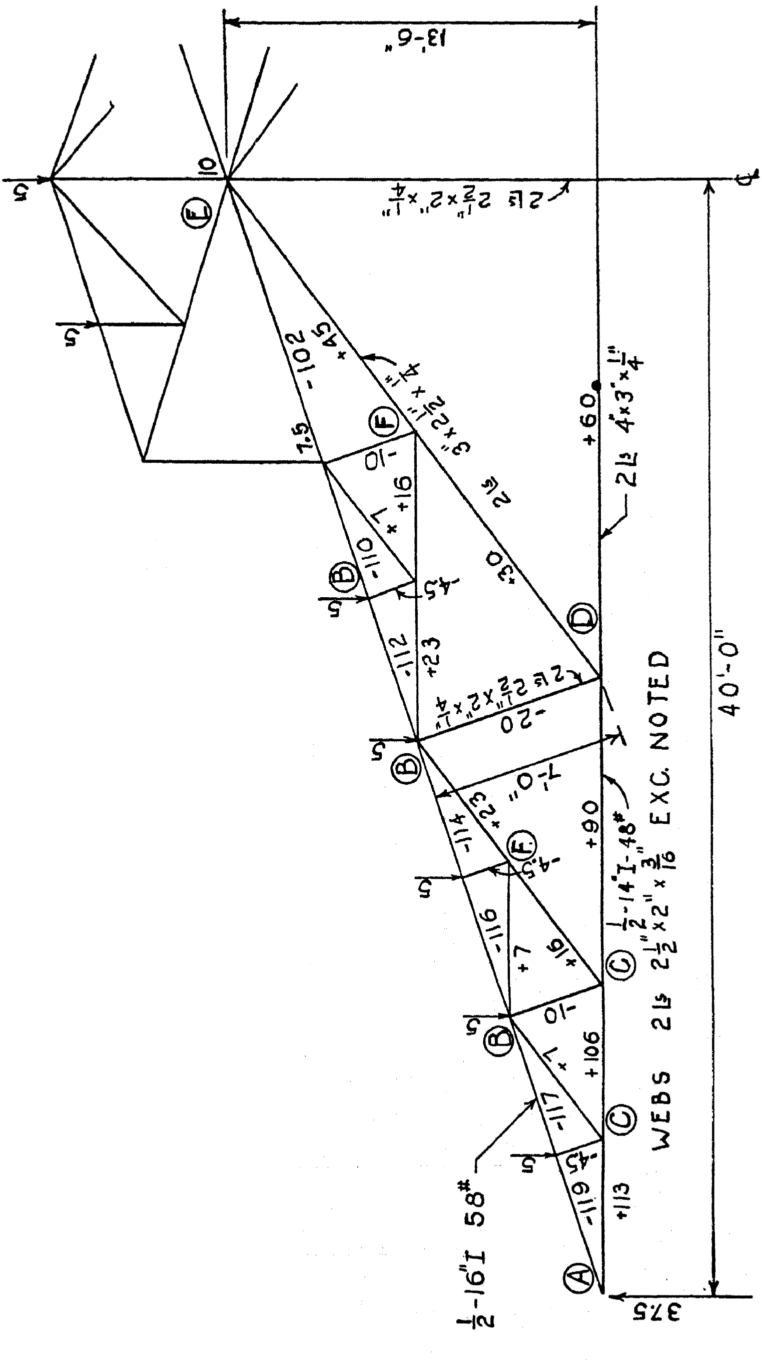

13'-6"
40'-0"
WEBS 2Ls 2½"x2"x3/16" EXC. NOTED
½-16"I 58#
½-14"I-48#
2Ls 4"x3"x¼"
2Ls 3"x2½"x¼"
2Ls 2½"x2"x¼"
7'-0"
37.5

Fig. 868.

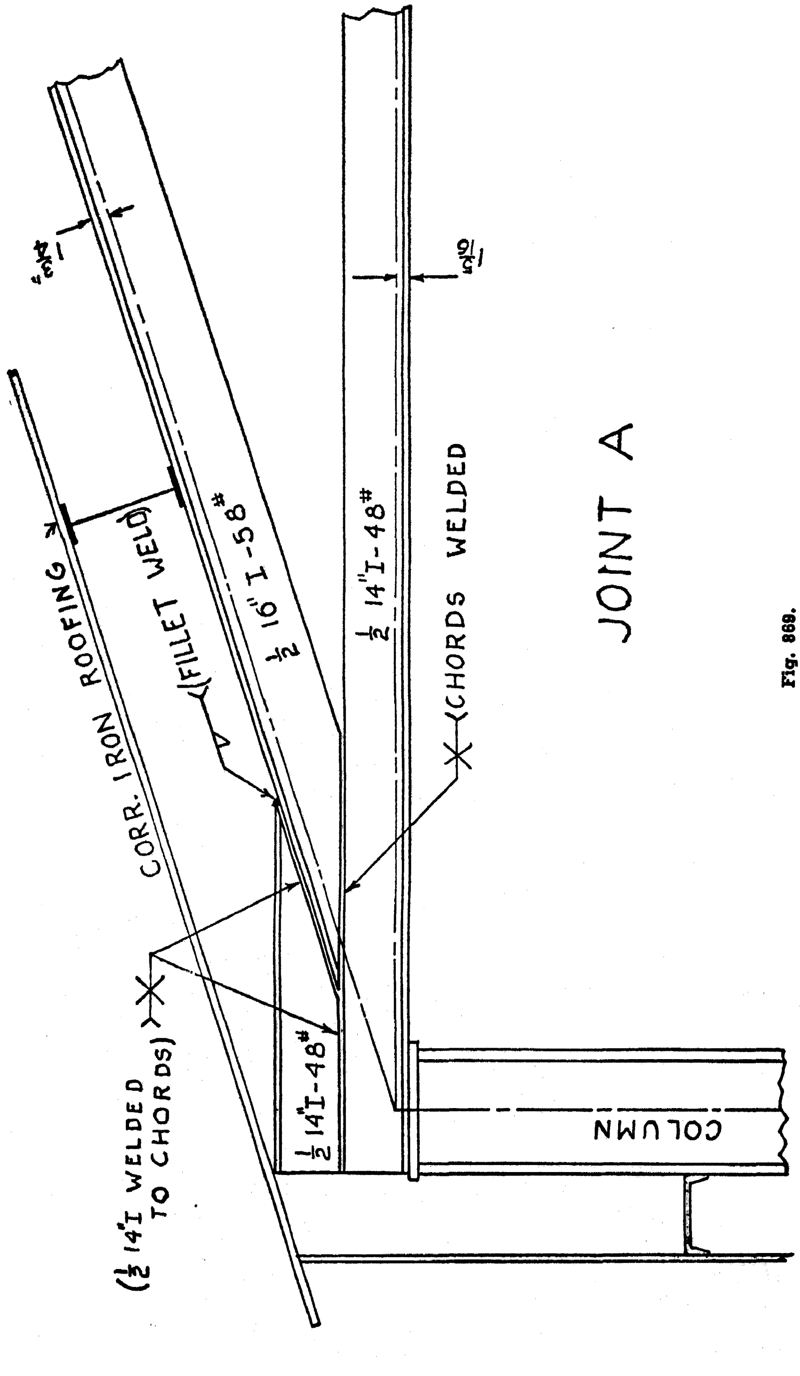

CORR. IRON ROOFING
(FILLET WELD)
½ 16" I-58#
½ 14" I-48#
CHORDS WELDED
JOINT A
(½ 14" I WELDED TO CHORDS)
½ 14" I-48#
COLUMN

Fig. 869.

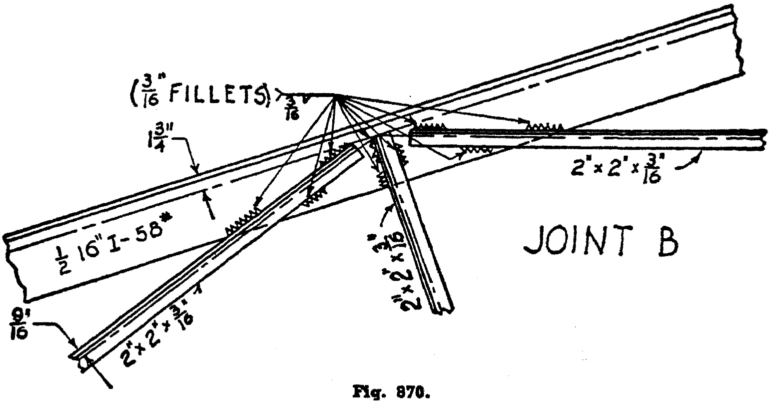


Fig. 870.

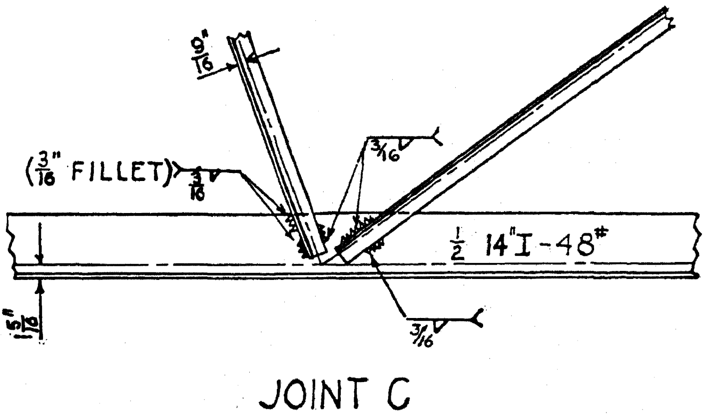


Fig. 871.

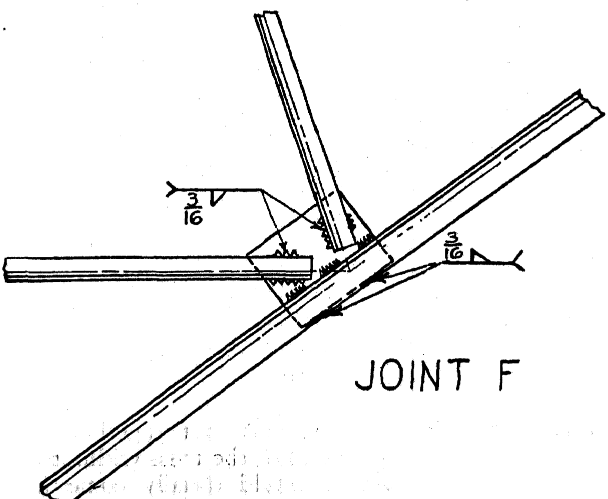


Fig. 872.

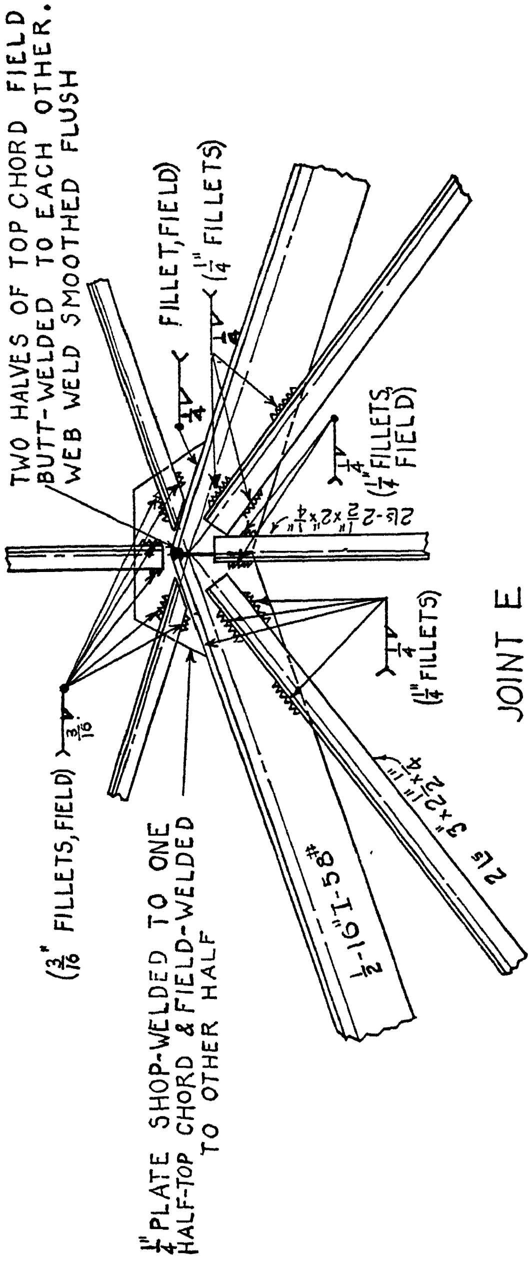


Fig. 873.

flange as illustrated. This arrangement, put together in the shop, gives the required strength to the end of the truss without necessitating the use of a knee brace, which would usually come in the crane clearance. If the connection to the column is field-welded with the

shielded arc, a very rigid connection is provided. The welding of this type of truss consists generally of short, light fillets. Figs. 870, 871 and 872 show the welding at joints B, C and F respectively, all short sections of $\frac{3}{16}''$ fillets. The fact that the web diagonals connect to the chords at a very flat angle provides all the welding space required without crowding.

Fig. 873 shows the center top chord joint: the two chord sections

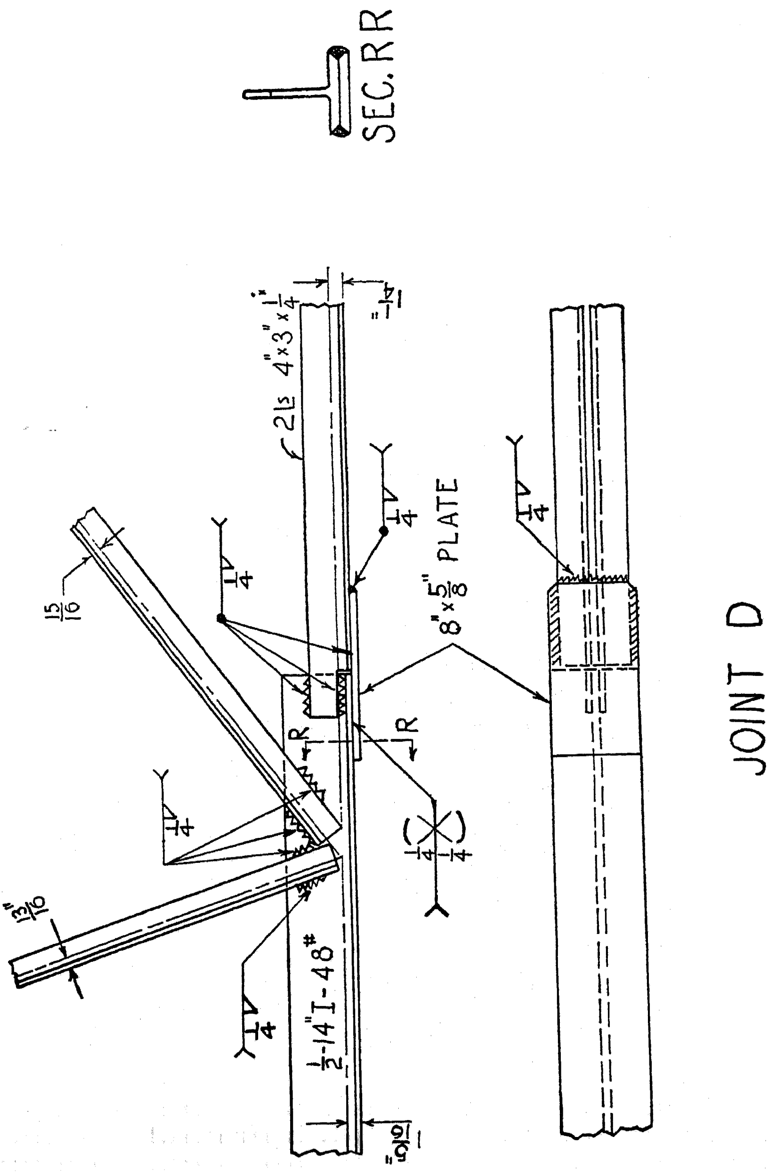


Fig. 874.

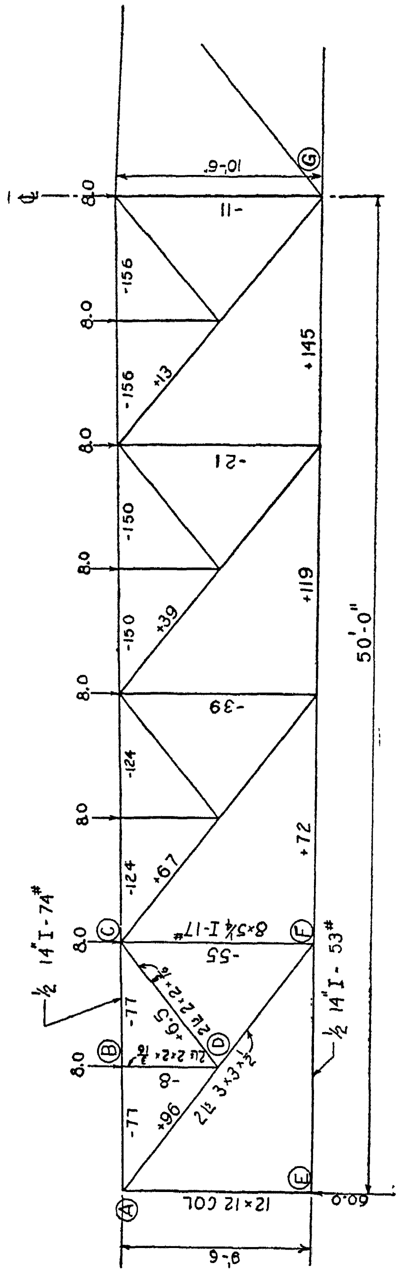


Fig. 875.

are field-butt-welded together, care being taken that the correct distance between column connection holes is maintained. The center vertical is then welded on and, after the truss is erected, the monitor

ties and struts are welded to the 1/4" connection plate which has been shop-welded to one of the segments of the top chord.

Fig. 874 shows the field splice in the bottom chord at joints D.

Fig. 875 shows a 100 ft. roof truss of the type commonly used for "high-low" roof construction, viz. one or more bays with the roof at the level of the top chord followed by one bay at the level of the bottom chord. This too is a common mill roof truss, with subdivided top chord panels. The chords are T sections made from split I-beams. The connection to supporting columns is shown in Fig. 876: the 5" x 3 1/2" angles provide a seat to the column top which is a horizontal surface, the setting of the angles rectifying the slope of the top chord T.

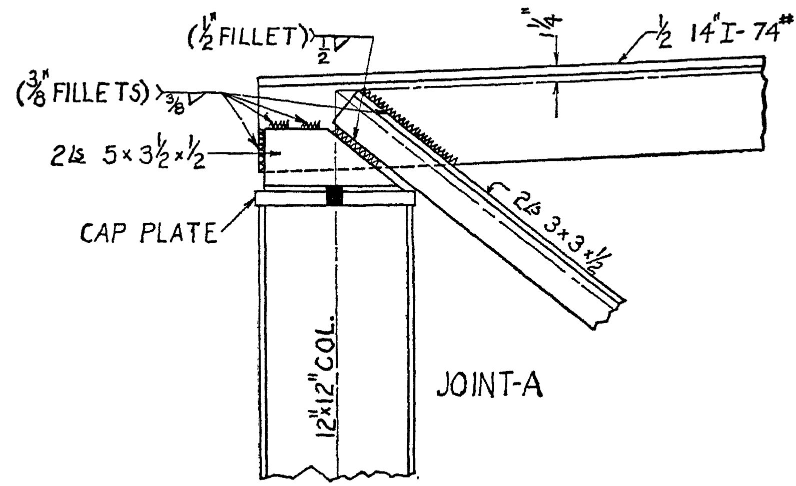


Fig. 876.

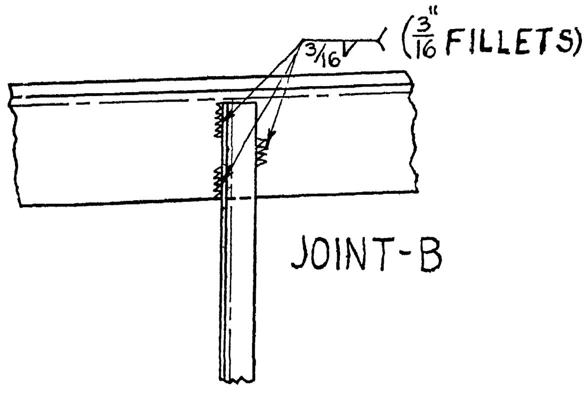


Fig. 877.

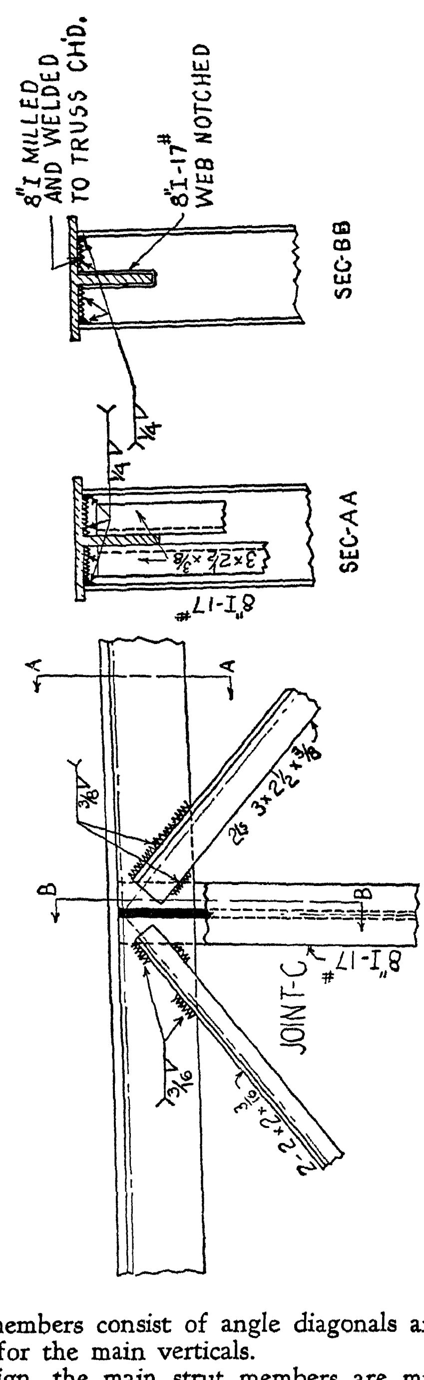


Fig. 878.

The web members consist of angle diagonals and sub-struts and beam sections for the main verticals.

In this design, the main strut members are milled at each end

so as to fit snugly against the flange of the chord T's; they are welded to these T flanges only. This arrangement minimizes the welding of the main struts to the chords; permits the distribution of the welding heat to both flange and web of the chords at the main panel points; simplifies camber allowances at the joints and leaves plenty of room for welding-on the diagonals. These features can be observed by a study of Fig. 878, showing connections at joint C and Figs. 879 and 880, showing the details at joints F and G respectively.

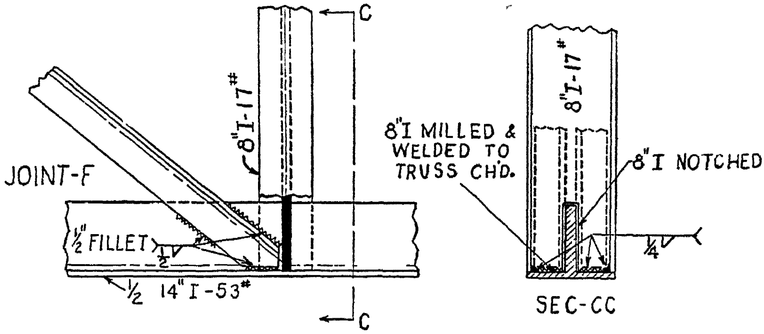


Fig. 879.

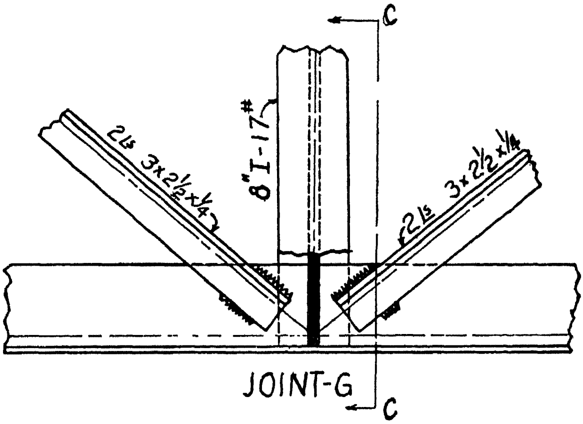


Fig. 880.

Fig. 881 shows sub-panel joints D. A ⅜″ gusset plate is here introduced as it is the simple straightforward thing to do. This plate is suitably connected by fillet and butt-welds to the main diagonals and gives ample room for the connection of sub-verticals and sub-diagonals as illustrated.

The bottom chord connection to the column seat is shown by Fig. 882.

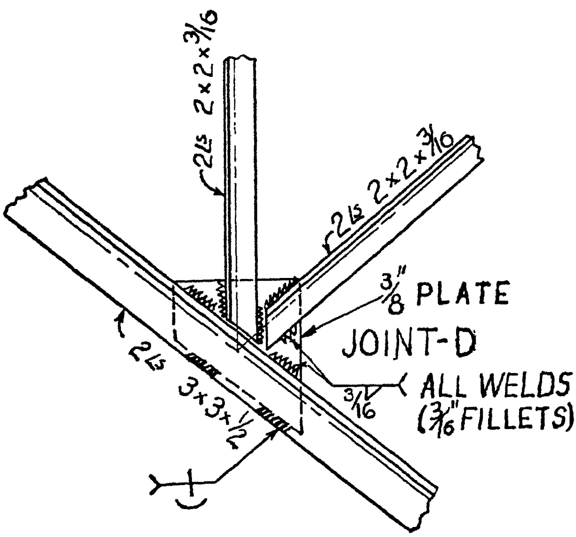


Fig. 881.

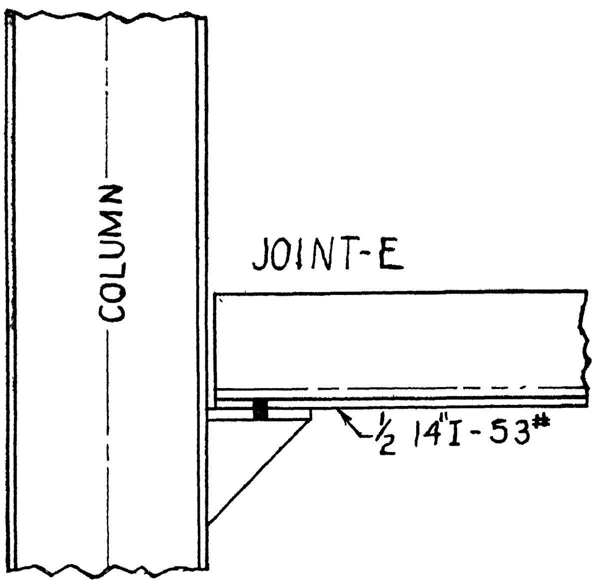


Fig. 882.

Fig. 883 shows the outline of an 80 ft. truss adapted to roofs with or without a monitor. The particular arrangement shown has no monitor.

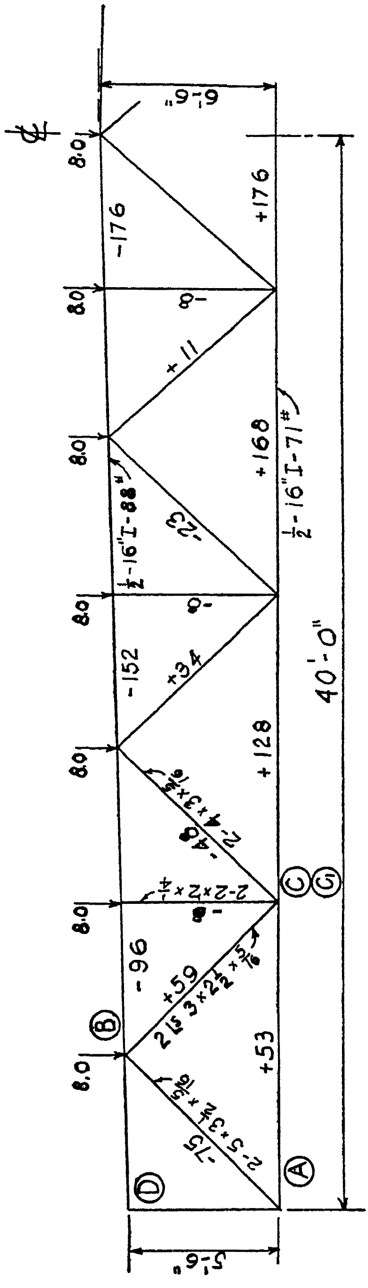


Fig. 883.

The end diagonals, in this design, are made compression members in order to develop a large moment capacity at the column connections to resist side sway due to cranes or to wind or to both.

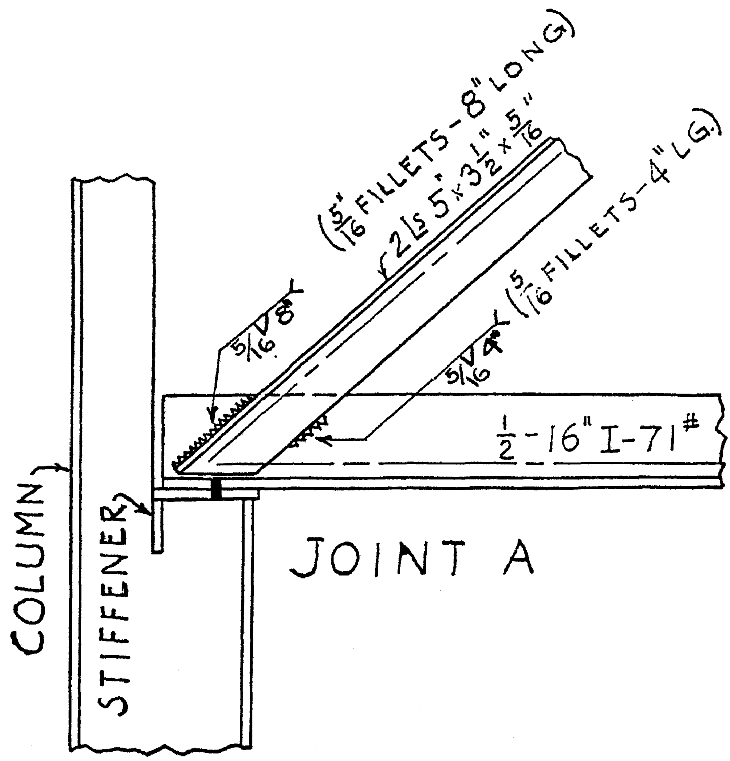


Fig. 884.

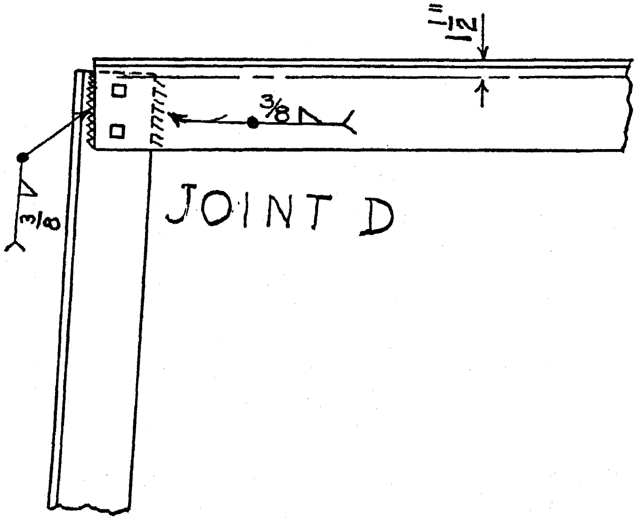


Fig. 885.

Figs. 884 and 885 show the supporting column notched to provide room for a field-welded seat at the bottom chord level, the upper part of the column between truss chords being T-shaped. It is evident that additional column stiffness may readily be obtained by providing a shop-welded plate to change the T-shape of the upper column section to an I-shape, this plate being forked at the bottom to act as a stiffener, replacing those shown in Fig. 884.

The inclination of the diagonals gives a suitable amount of room (Fig. 886) for connections at panel points where two diagonals meet. At joints C, the verticals, carrying in this case only 8,000 lbs., can be welded between the diagonals, but (Fig. 887) there is no room to spare. This condition suggests, for cases where three members converge and where the welding of the vertical requires ample room, the arrangement shown in Fig. 888. The crowded condition, Fig. 887,

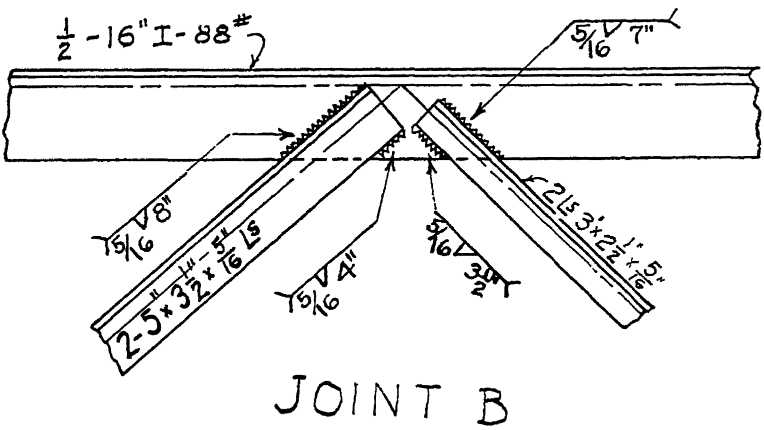


Fig. 886.

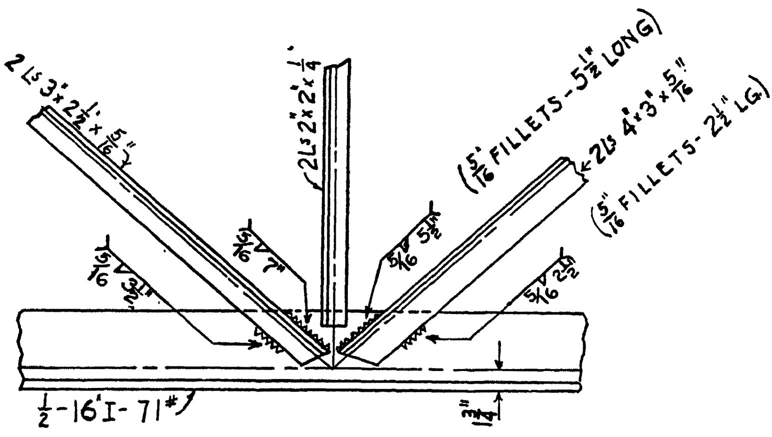


Fig. 887.

is due to the location of the point of intersection of the gravity lines of the bottom chord with that of the diagonals. If a compound bottom chord, Fig. 888, is used, which "pulls down" the chord and diagonal gravity line intersection, more space is obtained between the diagonals so that considerable welding space is obtained for the vertical.

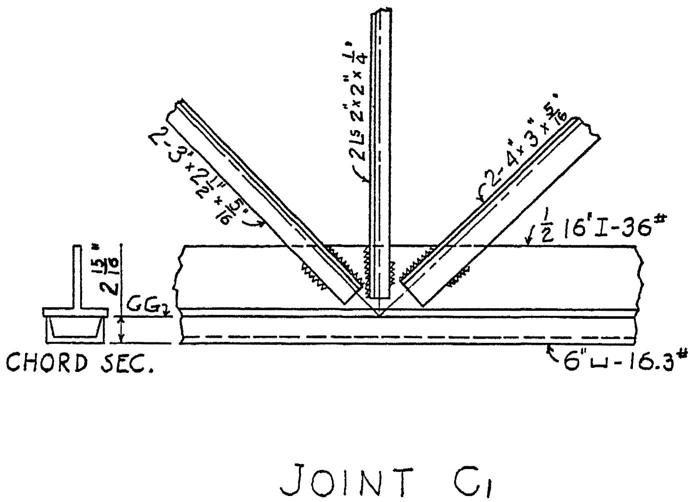


Fig. 888.

Figure 889 shows diagrammatically a 60 ft. truss designed for both top and bottom chord simultaneous loading. To obtain rigidity, the truss is made N-shape and has more depth than is usually given 60 ft. trusses. Even then, the chord stresses run fairly high.

The chords are of the double T type so as to distribute the welding of the web members.

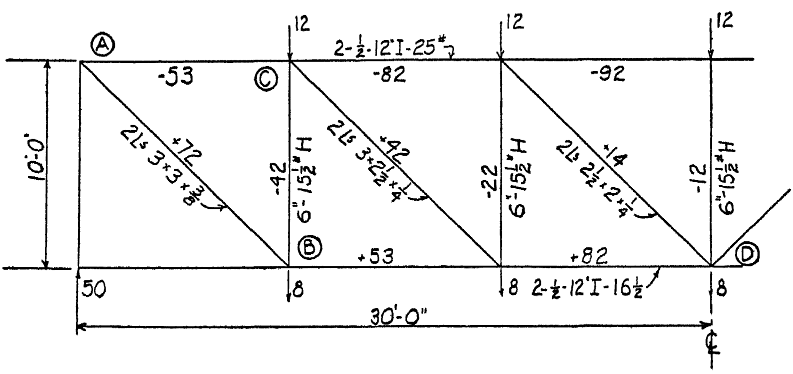


Fig. 889.

It is to be noted that a compression member consisting of a single T with a deep web provides a good welding surface for the web members on that deep web but such a deep-webbed T is a poor compression member if all of its cross-section is figured to take compression. That part of the web which is within reasonable distance of the flange is braced, more or less against lateral flexure, but that condition does not apply to that part of the deep web which is far removed from the bracing influence of the flange.

With that point of view in mind, the top flange of the truss shown in Fig. 889 is made up of two short-web T's. The bottom chord is made up of similar sections to facilitate assembling. The verticals are 6″ x 6″ columns set inside the webs of the double chord T's. The diagonals are pairs of angles set outside the chord webs. Occasional plate stiffeners should be provided between the chord T's to keep their spacing constant.

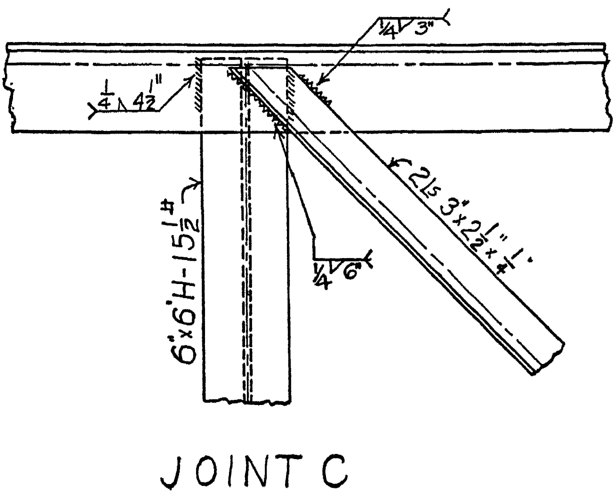


Fig. 890.

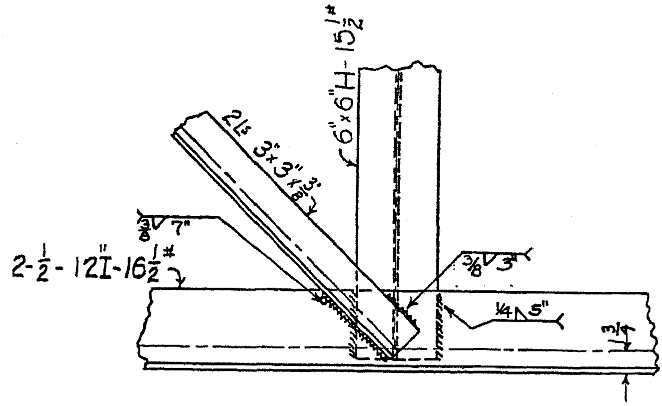
Fig. 890 shows the position of the web members and the welding at the top chord joints C while Fig. 891 shows the corresponding arrangement at bottom chord panel points B. The welding is indicated by the new welding symbols of the American Welding Society.

Fig. 892 shows the relative position of chord and web members at the center of the bottom chord. It is to be remembered that 60 ft. trusses are now normally shipped in one piece from fabricating plants.

Fig. 893 shows a simple column connection. The column shown is a 10″ x 8″ section. A short piece of the same column section is shop-welded between the chord webs and field-connected, first by bolts, to the top of the column shaft and, later, field-welded to it.

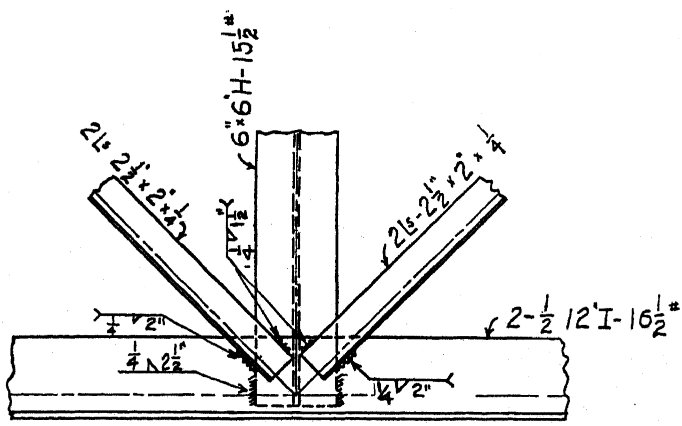
The connection of the truss bottom chord to the column is similar to that shown in Fig. 882.

Arc-welded trusses are very well adapted to structures where clean lines, light appearance and neatness are desirable.



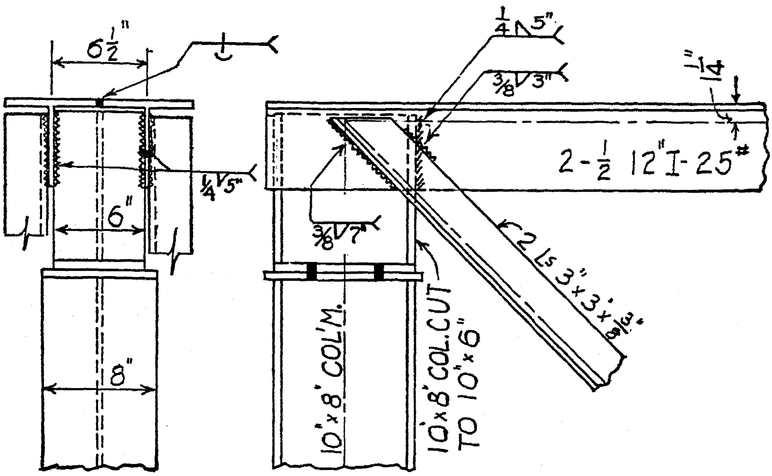
JOINT B

Fig. 891.



JOINT D

Fig. 892.



JOINT A

Fig. 893.

A truss span of 80 feet over a craneway is shown in Fig. 894. The truss chords are made of T's formed by splitting I-beams longitudinally; the web members are angles. The absence of gussets gives an appearance of neatness and lightness that are very pleasing. There is less light interference. These trusses are more than 25% lighter than conventional riveted trusses designed for the same duty.

Fig. 894.

Close-up view of a 106 ft. arc-welded truss, 11′-4″ deep, weighing $7\frac{1}{2}$ tons is shown in Fig. 895. Both chord and web members are made of T sections obtained by splitting I-beams. The compact joint design is very noteworthy. In spite of its great size, the truss is neat and graceful owing to the absence of gusset plates and, again, a saving of more than 20% in weight is obtained over a corresponding design for riveting.

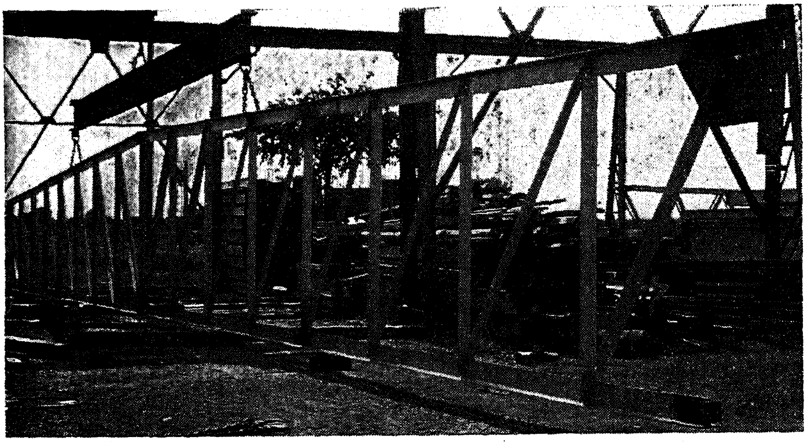


Fig. 895.

Trusses over convention halls, gymnasiums, swimming pools, recreation rooms, auditoriums can be given graceful lines and, if arc-welded, provide neat outlines, pleasing to the eye and devoid of gusset plates.

Fig. 896 illustrates this subject very well. It shows quadrangular

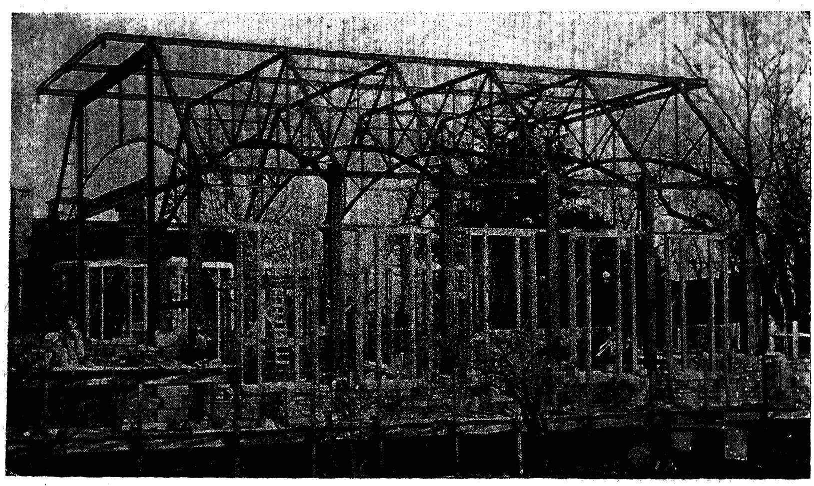


Fig. 896.

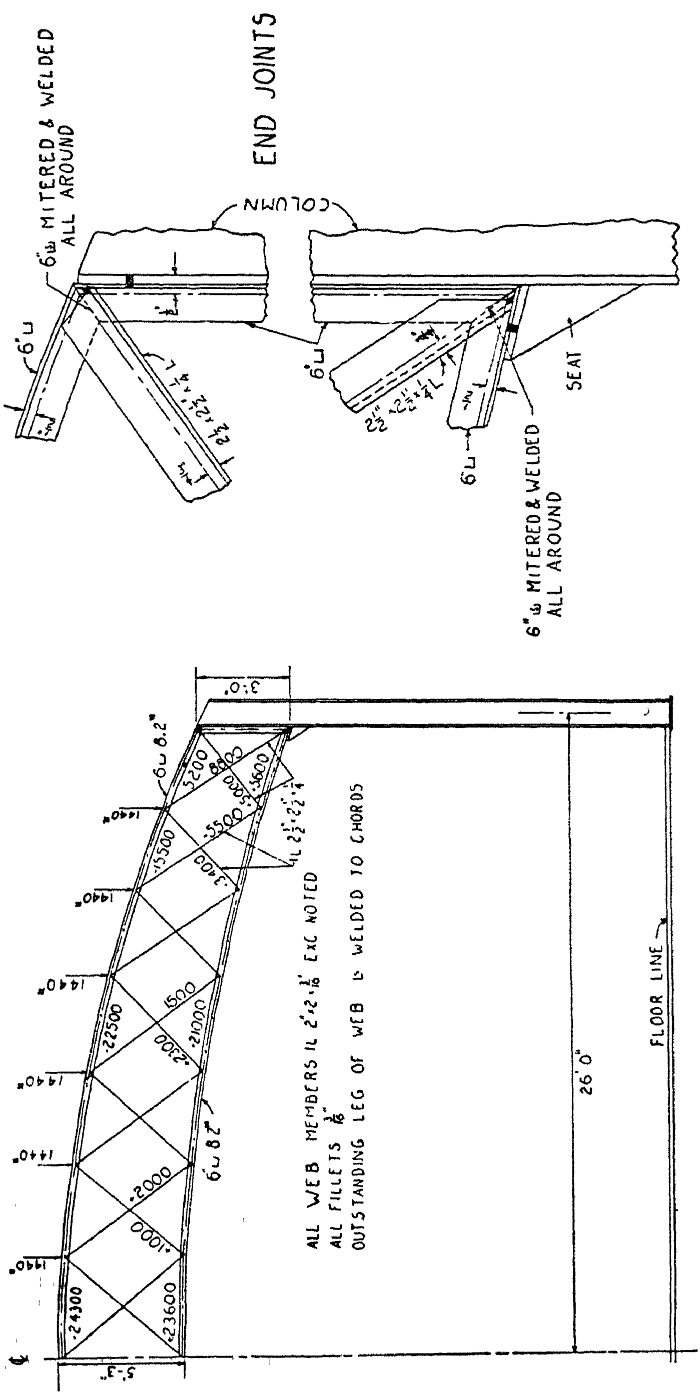

END JOINTS
6" MITERED & WELDED ALL AROUND
COLUMN
6" MITERED & WELDED ALL AROUND
SEAT
3'-0"
6" 8.2#
26'-0"
FLOOR LINE
5'-3"
ALL WEB MEMBERS 1L 2"×2"×1/4" EXC NOTED
ALL FILLETS 3/16"
OUTSTANDING LEG OF WEB WELDED TO CHORDS
1440#
-24300
-23600
-22500
-21000
-15500
-2000
-1000
5200
8800
5600
5500
3400
1500
2100

Fig. 897.

curved bottom chord trusses supporting the roof and ceiling of a hospital addition. Such trusses are easy to fabricate and readily allow the architect to obtain very desirable outlines at no special extra cost.

Fig. 897 left, shows a 52 ft. truss, lenticular in shape. The stresses are low and the welding is kept to a minimum. The chords are standard 6″ channels bent against their axis of least resistance. The outstanding leg of the diagonals (at right angles to the plane of the sheet) are shop-welded to the web of the chord channels. The leg of the web angles parallel to the plane of the sheet are not welded at their ends. All diagonals are welded to each other at their intersections, transferring web-to-web stresses directly from one web member to the next. (See Page 625.) The typical jointing of diagonals to the chords is shown in Fig. 898.

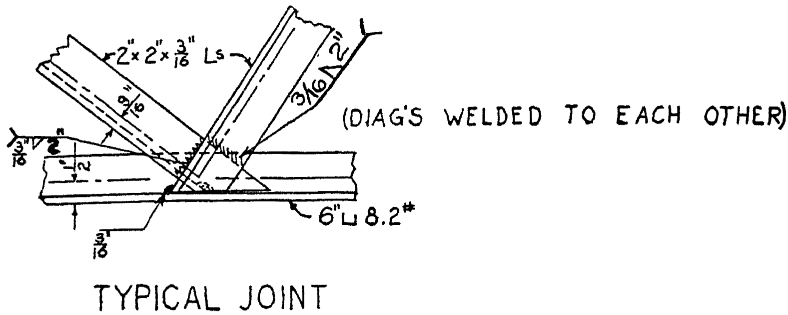


Fig. 898.

The end connection of the trusses to the columns is shown in Fig. 897, right: the columns are provided with a seat made from a half beam section shop-welded to the column. Two bolt holes are provided in this seat and two more in the column flange and end members of the trusses just below the top chord of the truss. These top and bottom bolts in themselves form a rigid connection of truss to column; this stiffness can be further increased by field-welding the trusses to the columns opposite both top and bottom truss chords.

Arc-welded trusses or frames are not limited to roof construction. When beam spans exceed conventional limits, these welded frames provide an excellent substitute for heavy rolled beams, decrease deflection and save money.

Consider, for instance, a thirty-two foot span floor that has to carry 150 lbs. live load plus a four inch concrete floor slab. If the supporting beams are spaced 6′-9″ apart, the load that each beam has to handle is $6\frac{3}{4} \times 32 \times 200 = 43{,}000$ lbs. This requires a 21″—59 lb. beam.

The frame shown in Fig. 899 will handle this load. It weighs 37 lbs. per foot, or 63% of the weight of the corresponding rolled beam.

Whenever the relation between the weight of a welded frame to the corresponding rolled beam is of this order, the welded frame is more economical.

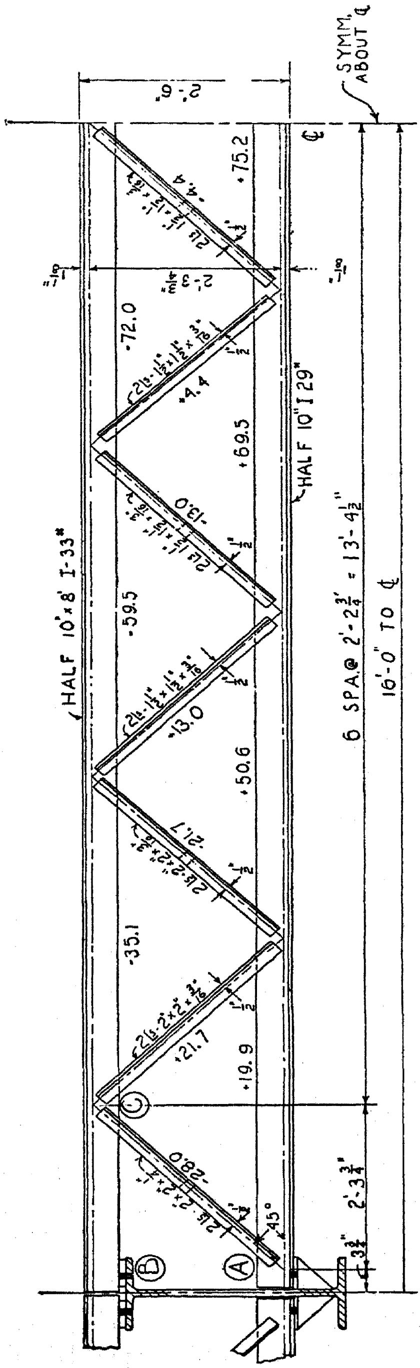

SYMM. ABOUT ℄
2'-6"
HALF 10"x8" I-33#
HALF 10" I 29#
6 SPA.@ 2'-2 3/4' = 13'-4 1/2"
16'-0" TO ℄
+75.2
-72.0
+69.5
-59.5
+50.6
-35.1
+19.9
+4.4
-13.0
+13.0
-21.7
+21.7
-28.0
45°
2'-3 3/4"
3 1/4"
A
B
C

Fig. 899.

An examination of Fig. 900 will bring out the simplicity of the details. At A, the frame rests on a seat attached to the supporting girder. The top flange connection shown at B consists of two bolts fastening the seat plate, shop-welded to the frame top flange, to the flange of the girder. The web angle connections to the chords are shown at C. Such connections cost no more than riveted connections —in fact they cost less since they permit the use of much lighter material. Frames of this kind are in active service in many establishments and are giving first class service.

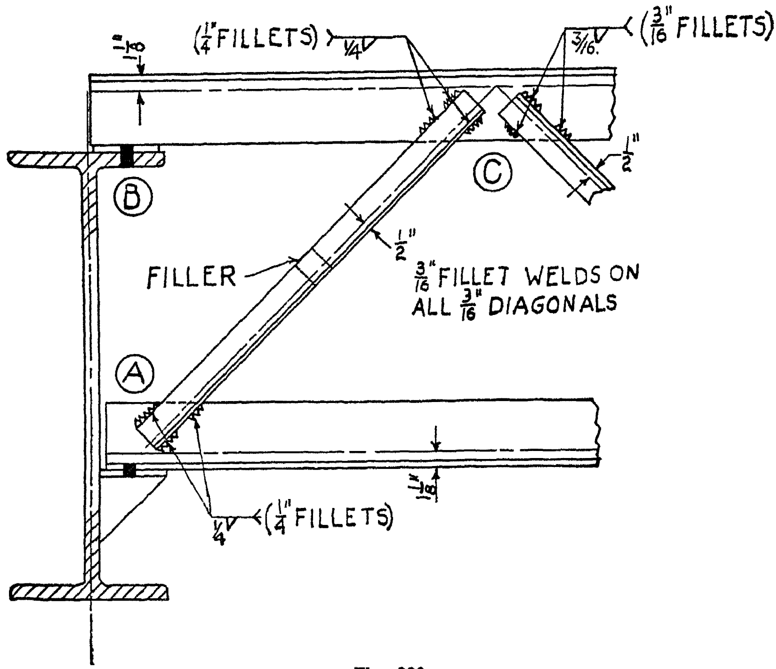


Fig. 900.

Rigid Frame Construction.—Manufacturing requirements have recently called for a large increase in the number of buildings in which the roof is supported by properly shaped beams instead of by trusses. Trusses are in the way of certain types of equipment such as large presses, dip tanks, suspended ovens and conveyors, whereas shaped beams clear such equipment without interference and permit better light through the roof.

A saw-tooth roof supported by conventional trusses is shown in Fig. 901. Superimposed on the truss is a shaped beam outline designed to support the same roof as the truss.

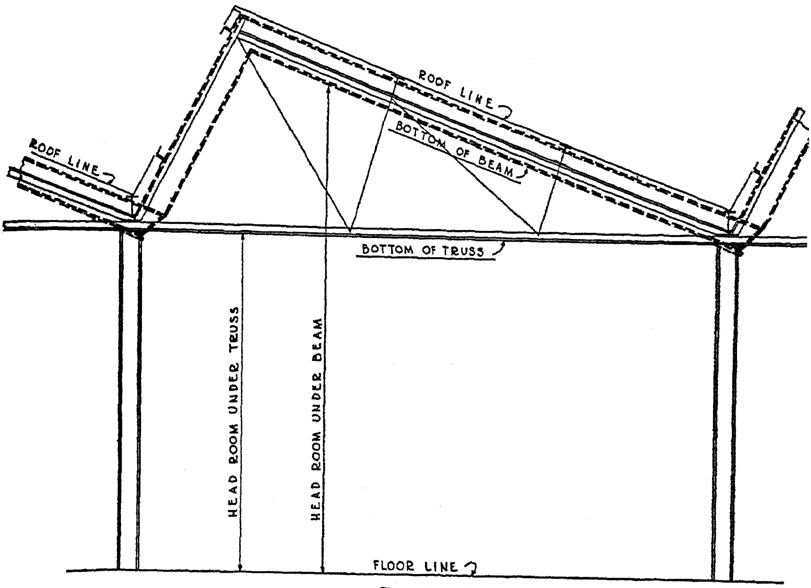


Fig. 901.

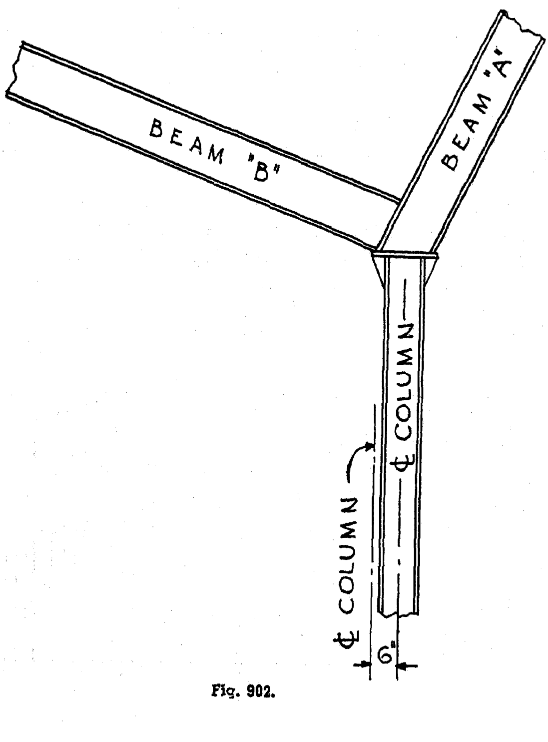


Fig. 902.

Fig. 903 shows a monitor type trussed roof and the corresponding shaped beam outline. It is apparent that the shaped beams do not increase the cubical content of the building since the roof outline does not change while the structural clearances limiting equipment and operations are greatly improved.

A little attention to detail will often improve the general layout and the connections. For instance, in Fig. 901, the clumsy detail at the top of the columns can be improved readily by shifting the location of the columns six inches; the result is shown in Fig. 902. Beam A is connected to the column cap while beam B frames to the end of Beam A.

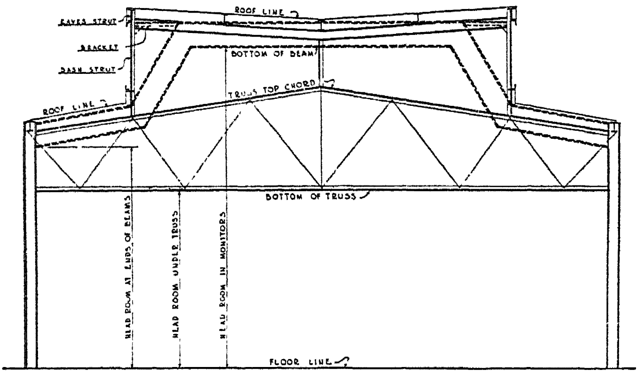


Fig. 903.

In Fig. 903, the monitor sash is vertical. The eaves struts and the top of the sash struts are therefore bracketed off the hip of the shaped beam as indicated.

Fig. 906-A illustrates an economical type of monitor roof made of two straight beams cantilevering over the column tops, the cantilever ends supporting a shaped beam forming the monitor frame. The field connections are at the points marked A.

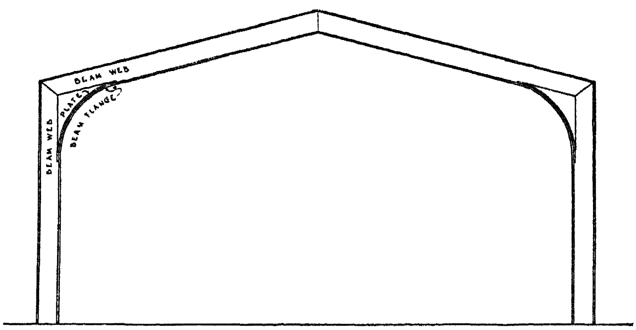


Fig. 904.

Fig. 906-B shows a monitor roof formed by a succession of straight and shaped beams. An abundance of light is obtained while two of the aisles provide liberal headroom for the accommodation of machinery and conveyors. The field splices are located at points B.

Fig. 904 shows an arch type structure readily fabricated from beams suitably shaped and formed. The forming is simple, being limited to the curving of the inner flange of the column sections after this flange has been separated from the web by flame-cutting. A triangular plate is inserted between the curved flange and the beam web after the curving of the flange has been completed and welded all around, thus avoiding unsightly splice plates.

A similar arch-type frame is shown in Fig. 905. The roof rafters and columns are in one piece, formed by V-notching the beams at the peak and at the hips, bending, welding the joints so-formed after which the hip joints' straight line brackets are arc-welded to each bent.

Fig. 905.

In all shaped beam construction, the bulk of the work should be done at the fabricator's shop. The erection then resolves itself into a simple beam and column job. This assures maximum speed and economy.

The structure shown in Fig. 907 (also see Figs. 1086 to 1090 incl.) is designed along the lines indicated by the dotted outline in Fig. 901, and by Fig. 904. It is a fine example of modern factory construction. The roof frame is just as clean cut as the floor frame; no trusses, no bracing to clutter up the graceful outline of the structure and, consequently, no obstruction to light nor to equipment.

It will be observed that the rafter splice is not made on the ridge line but off to one side. In this way, the curved ridge work is completely fabricated in the shop. Similarly, the curved work and rafter ends, Fig. 908, are shop-assembled to the columns, thus reducing the field work to a minimum.

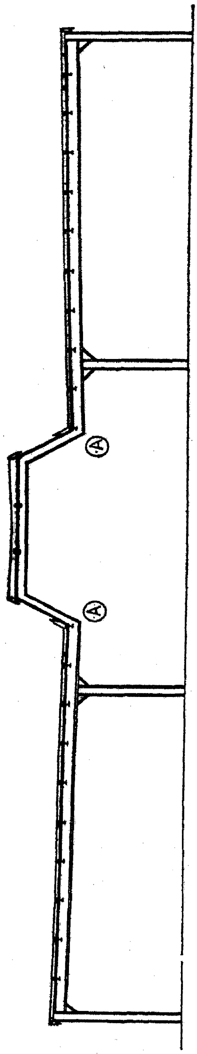


Fig. 906-A

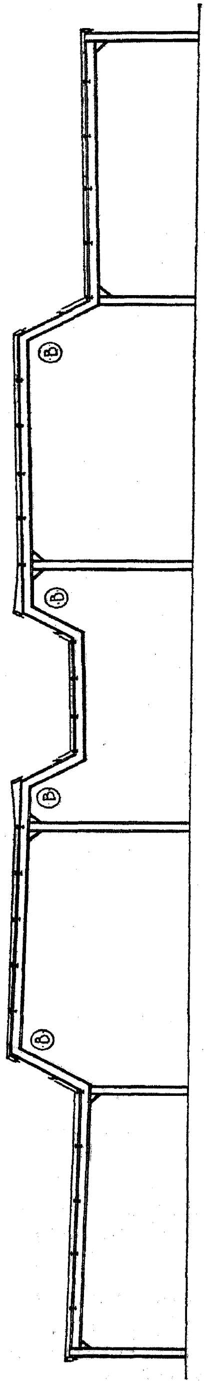


Fig. 906-B

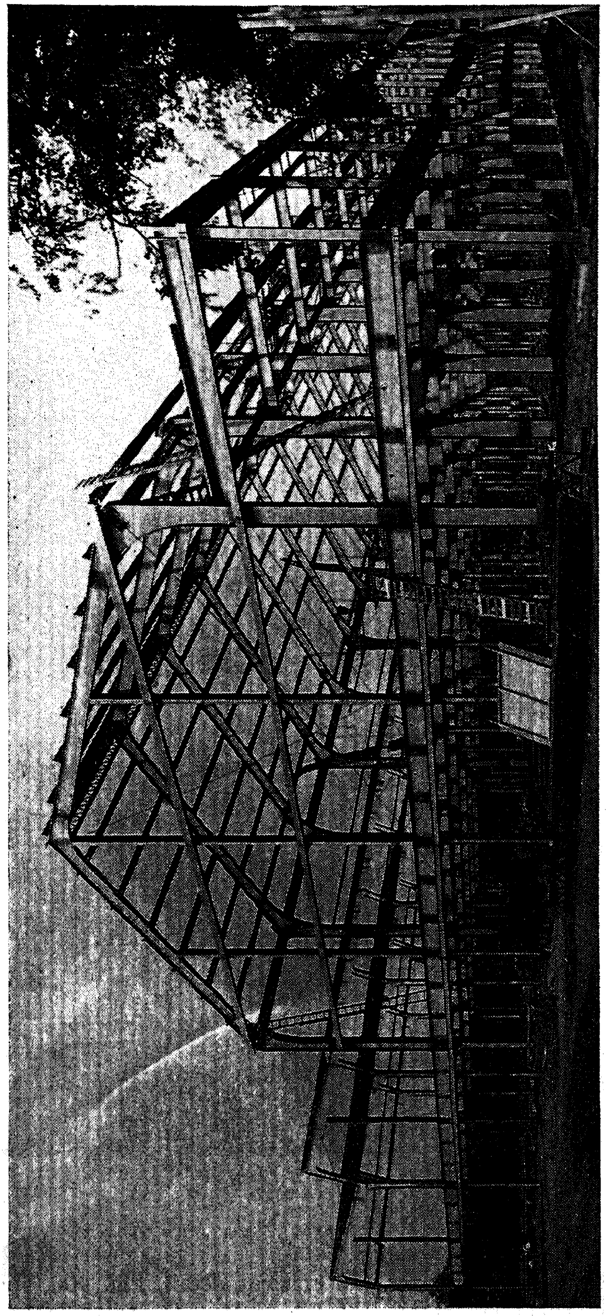


Fig. 907

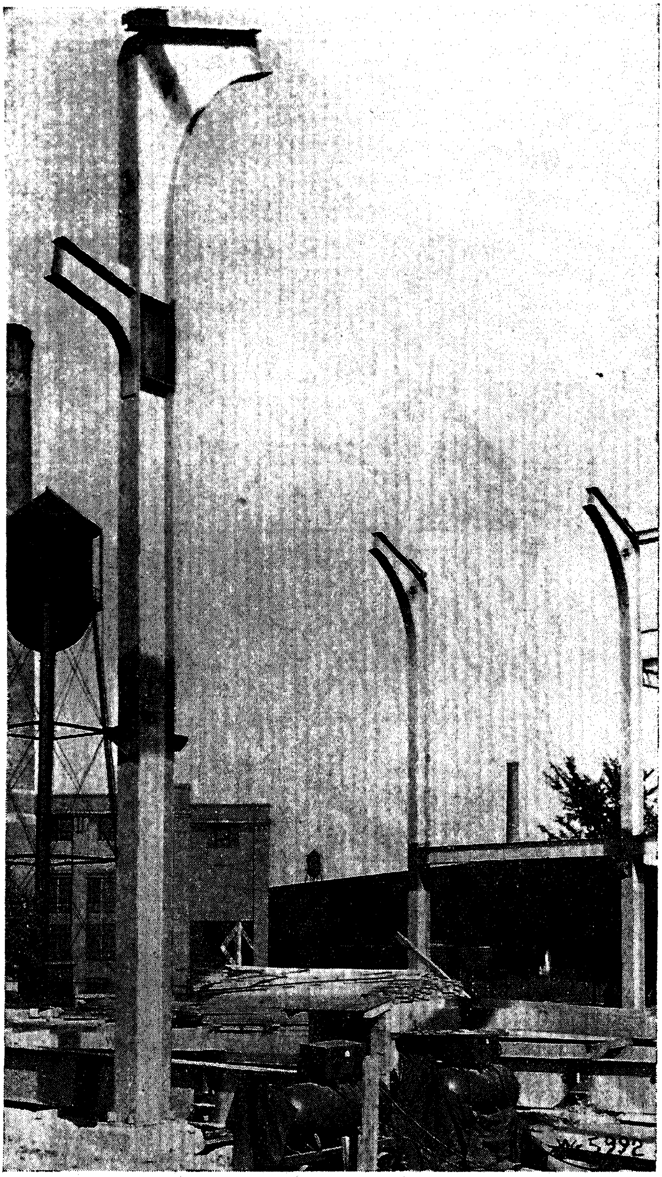


Fig. 908

Note the simple, compact and efficient detail, Fig. 908, for column anchor bolt attachment.

Other detail views of this building structure are shown in Figs. 907 and 910.

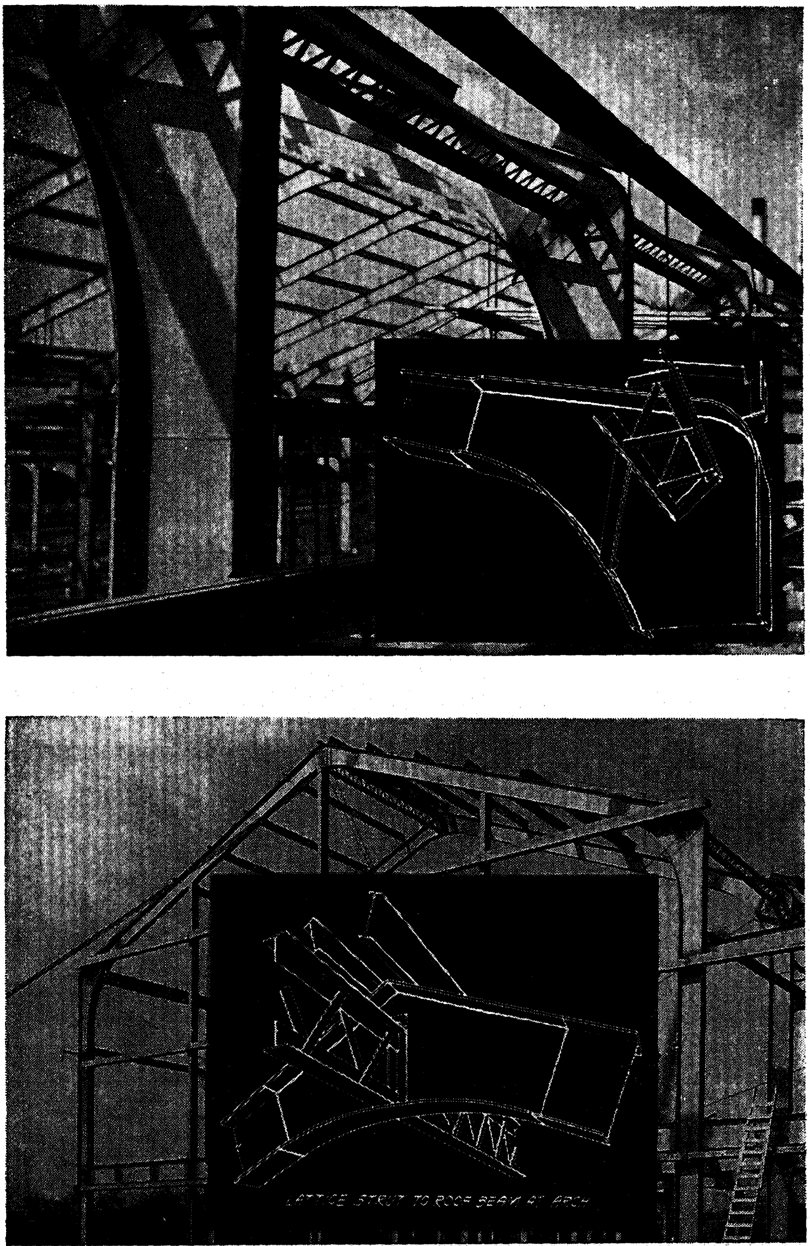
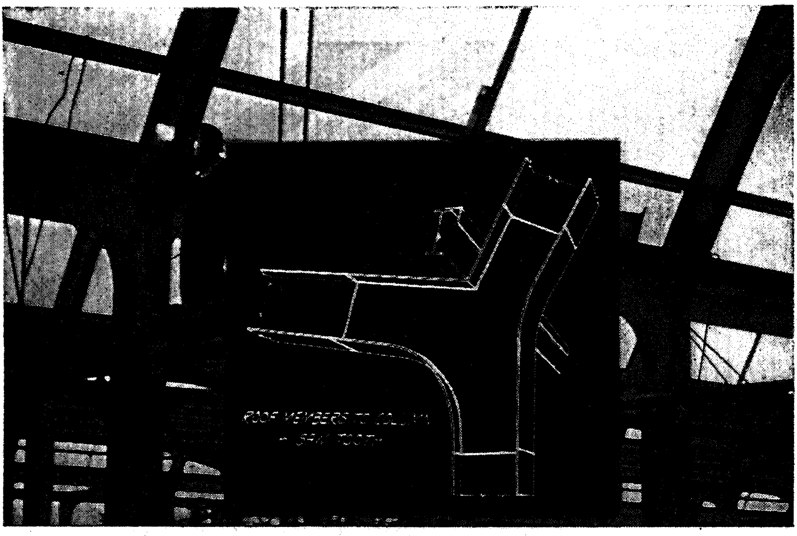


Fig. 909. Above: "Tree form" section branching from column into roof girder showing lattice strut. Below: Portion of steel framework of large main bay. Inset shows connection of lattice strut to fabricated roof beam at arch.



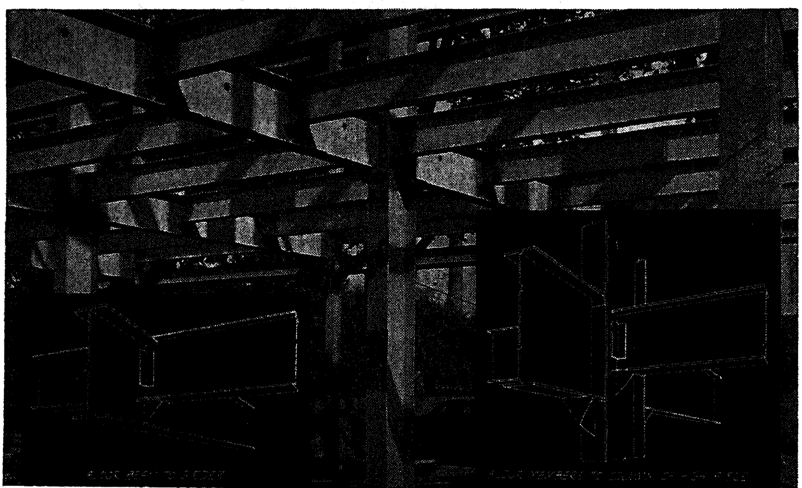


Fig. 910. Above: Arc welding the rafters. Erection view in the saw tooth section. Inset shows detail of "tree form" connection between column and roof members. Below: Details of second flooring of building shown in Fig. 907. Inset "A" shows connection of four members to column. Inset "B" shows floor beam to girder connection.

Fig. 912 shows a structure built according to the dotted outline shown in Fig. 903. These bent rafter beams are forty feet long and supported alternately by columns spaced forty feet apart or by longitudinal girders. Note the unobstructed view, devoid of trusses, frames or bracing, and the clear headroom available for machinery and conveyor installations. These rafters are shop-constructed in one piece

and erected as plain beams with welded connections to columns or girders.

The method of cutting the rafters to produce the curved bends for the lower joints beneath the monitors is shown in Fig. 911. The removed section of top flange and large upper V-section of web are shown in the foreground, together with the small truncated web section with curved sloping sides adjacent to the bottom flange. When the rafter is bent, the two curved cuts of the web roll on the bottom

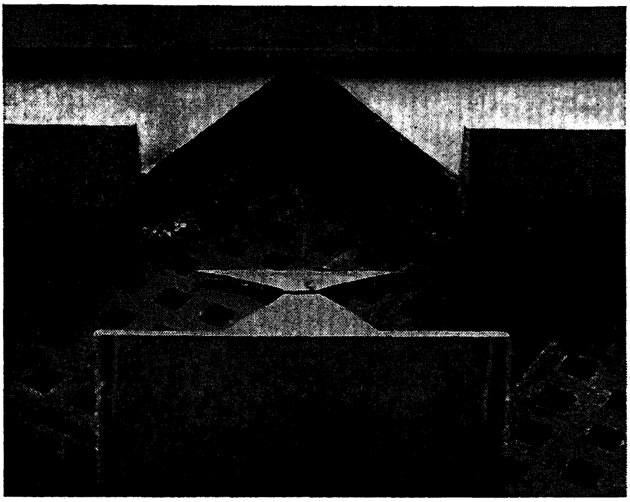


Fig. 911.

Fig. 912.

flange as the upper flange sections come together, giving the desired bottom flange curve. A detail of a completed lower curved joint is shown in Fig. 913, including stiffener bars to keep the flanges in proper spacing.

One of the top joints, located above the monitor sash is shown in Fig. 914. The bottom flange is in the foreground. The stiffener bar

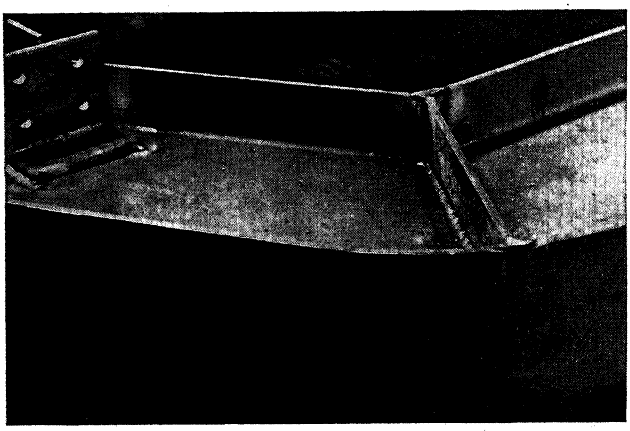


Fig. 913.

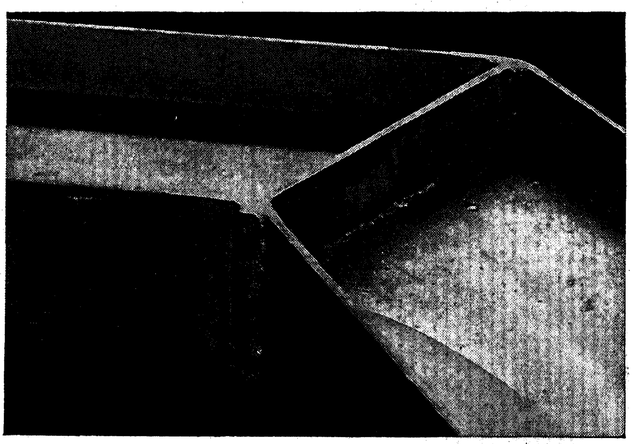


Fig. 914.

is a single through plate extending across the web and across the bottom flange of the rafters. It is welded to both sides of the bottom flange and to the rafter web, generally with comparatively small fillet welds, while the connection to the underside of the top flange usually requires a substantial fillet. The top flange is uninterrupted and bent sharply, requiring but a simple V-cut of the rafter to produce.

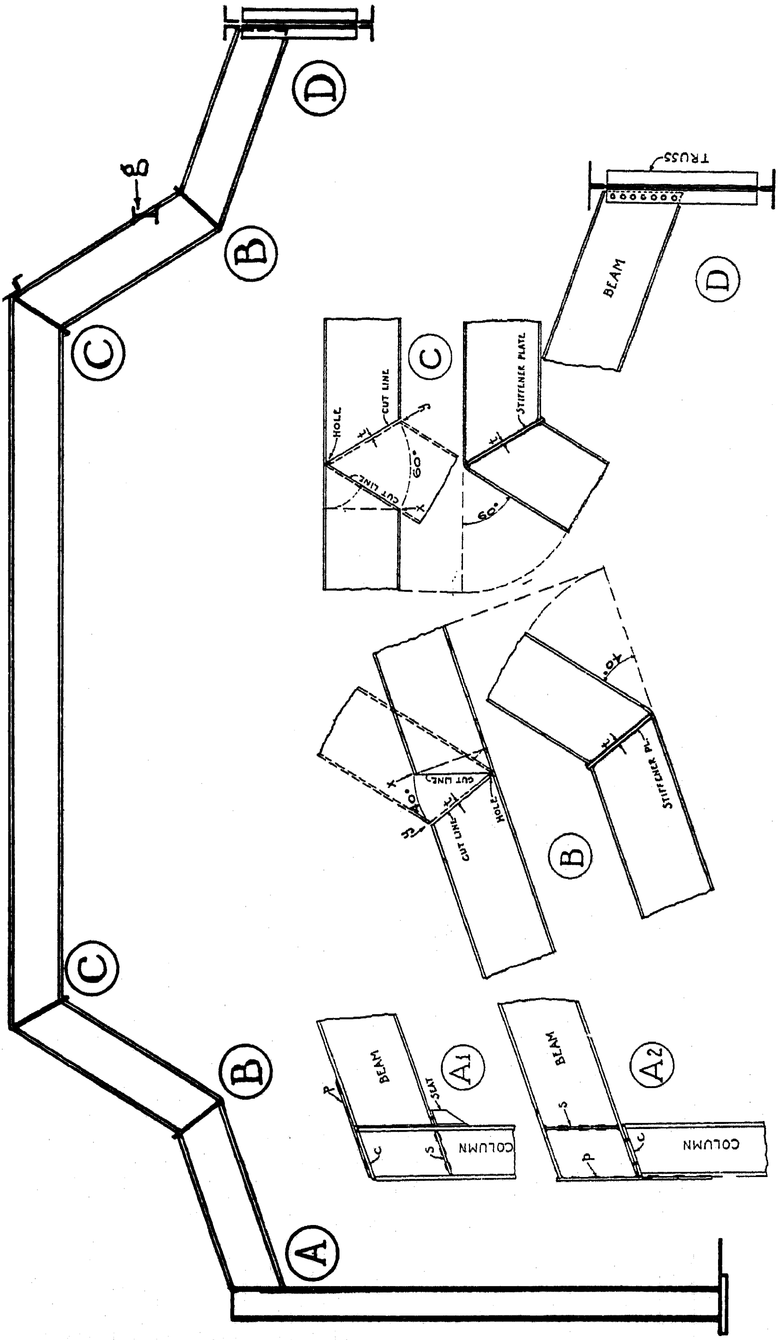

A
B
C
C
B
D
A1
A2
BEAM
BEAM
COLUMN
COLUMN
SEAT
HOLE
CUT LINE
CUT LINE
STIFFENER PLATE
STIFFENER PL.
60°
60°
40°
40°
BEAM
TRUSS
D

Fig. 915.

A beam fashioned to the shape of a monitor roof is shown in Fig. 915. In this type of construction, if no lateral support is available at the ends of the beam, a rigid connection to the column should be provided. Two such connections are indicated. At "A1", the beam is erected on a seat shop-welded to the column. The end of the beam's bottom flange is butt-welded in the field to the face of the column which is backed by stiffeners "s". The top of the column is provided with a shop-welded cap plate "c"; to this cap and to the top flange of the beam, a connection plate "p" is field-welded, producing a rigid connection of beam to column.

Another method of producing a rigid connection is shown at "A2". The beam is erected on top of a shop-welded cap plate "c". Stiffeners "s" are shop-welded to the beam and splice plate "p" is field-welded to the outer face of the column and to the end of the beam.

Joints "B" and "C" are made in the shop; the beam is shipped in one piece. Joint "B" is produced as follows: first, the beam flange is cut all the way across at "x" and "y"; a hole equal in diameter to the thickness "t" of the stiffener plate is then drilled. From this hole, the web is flame-cut, V-shape, at an angle equal to the bend angle. A stiffener plate of thickness "t" and equal in width to the beam flange is then set against one side of the V-cut and tacked to the web. The beam is then bent until

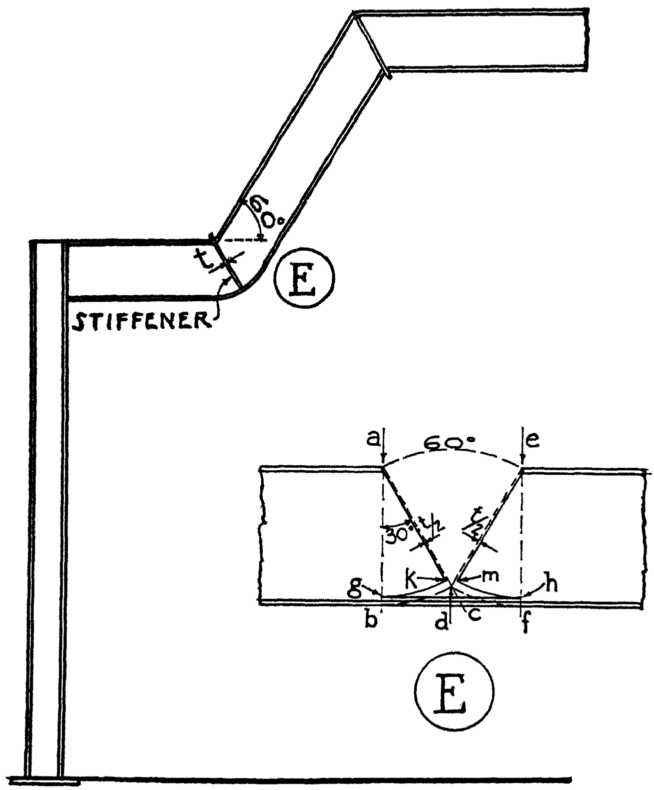


Fig. 916.

point "x" reaches point "y" when the stiffener is tacked to the other side of the V-cut, holding the bend in correct position. The stiffener is now welded as shown to the web and to the flanges, completing the joint.

If, instead of framing to a column, as at "A", Fig. 915, the end of the monitor beam frames to a truss or to a girder, as at "D", Fig. 915, provision must be made for the horizontal thrust of the beam. This may be accomplished by horizontal bracing between the top flange of the truss or girder and an adjacent purlin, such as "g", Fig. 915, transferring the thrust from the truss or girder to its supporting column.

Instead of a single span, as pictured in Fig. 915, if several successive monitor-shape beams are required side by side (Fig. 912), the beam thrusts on intermediate supports will substantially balance each other. But, along the edges of the structure, some suitable provision must be made to resist the outward thrust of the beams.

At "B", Fig. 915, a sharp bend is shown. A rounded bend, as illustrated in Fig. 916, detail "E" is sometimes desirable.

To produce a sixty degree curved bend, draw a straight line "a-b" across the beam and a line "a-c" making a thirty degree angle with "a-b". With "a" as a center, draw arc "b-d". From "d", draw line "d-e" and from "e", draw a line "e-f", parallel to "a-b". On "a-b", mark point "g" just above the fillet of the beam's lower flange; similarly, mark point "h" on line "e-f".

Draw a chalk line "g-h" on the beam. Parallel to "a-c" and to "e-d", draw chalk lines back one half the stiffener plate's thickness, "t". With center at "a", draw a curved chalk line "g-k" and, with center at "e", a curved chalk line "h-m". Flame-cut the web on the chalk lines and cut the top flange squarely across at "a" and at "e".

When point "e" rotates toward "a", "g-k" and "h-m" will roll on line "g-h" while lines "a-k" and "e-m", together with the flange cuts at "a" and at "e", close in. These will remain just far enough apart to allow for the thickness of the stiffener plate shown in Fig. 916.

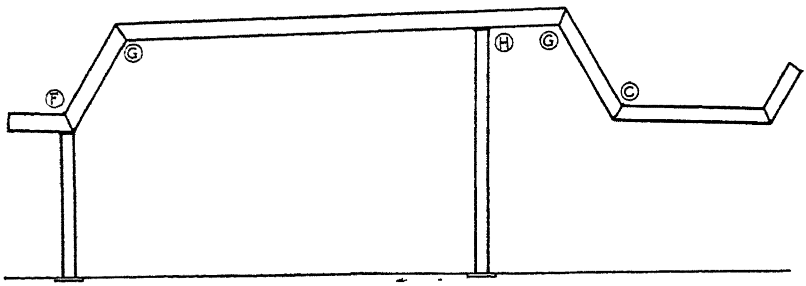
An enlarged view of part of the roof outline shown in Fig. 907, is shown in Fig. 917. Joints "C" and "F" are made in the shop. Connections at "G" and "H" are made in the field. The beam between successive points "G", therefore, it is a straight element set on a suitable slope to shed water.

The bends at "C" and at "F" are exactly the same as the one detailed at "C", Fig. 915, turned upside down.

The beam-to-column connection at "F" is made by means of a cap plate "c", shop-welded to the column top. The bottom flange of the beam is first field-bolted to the column top and, when the structure has been plumbed, the beam is field-welded to the cap plate.

The column connection at "H" is similar to the one at "F".

Detail "G" shows the field connections. Two connection plates are used. The one on the near side is shop-welded to beam "R" and provided with four open holes, two of which also pass through beam "R". The plate on the far side is shop-welded to beam "S" and is also provided with four holes, two of which also pass through beam "S". This arrangement permits easy erection and bolting. After the structure



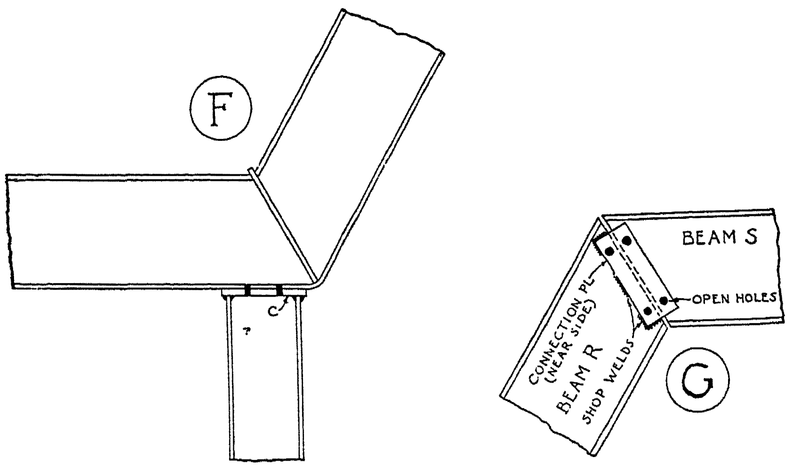


Fig. 917.

has been plumbed, the near connection plate is field-welded to beam "S" and the far plate, to beam "R".

A segmental arch roof of pleasing appearance is shown in Fig. 918. The 15 degree bends at "J" and at "K" are made in the shop. They are similar to the 40 degree bend shown at "B", Fig. 915, when read upside down.

The field connections are made at points "L". They are provided with two splice plates as described above for detail "G", Fig. 917.

There are two methods of fabricating in the top of the column, detail "I". One of them is shown at "I-1". In this case, both the beam and the column are cut off square on lines "u y" and "w x" respectively; the connecting element is a three-plate assembly joining the beam to the column.

This assembly consists of a web plate "u v w x y", with a curved bottom "x y", a top flange plate "u w", bent sharply at "v" and a curved bottom flange plate "x y". These three plates are shop-welded together along lines "u v w" and "x y". The assembly is shop-welded to the column on line "w x", the flanges being shop-welded to the

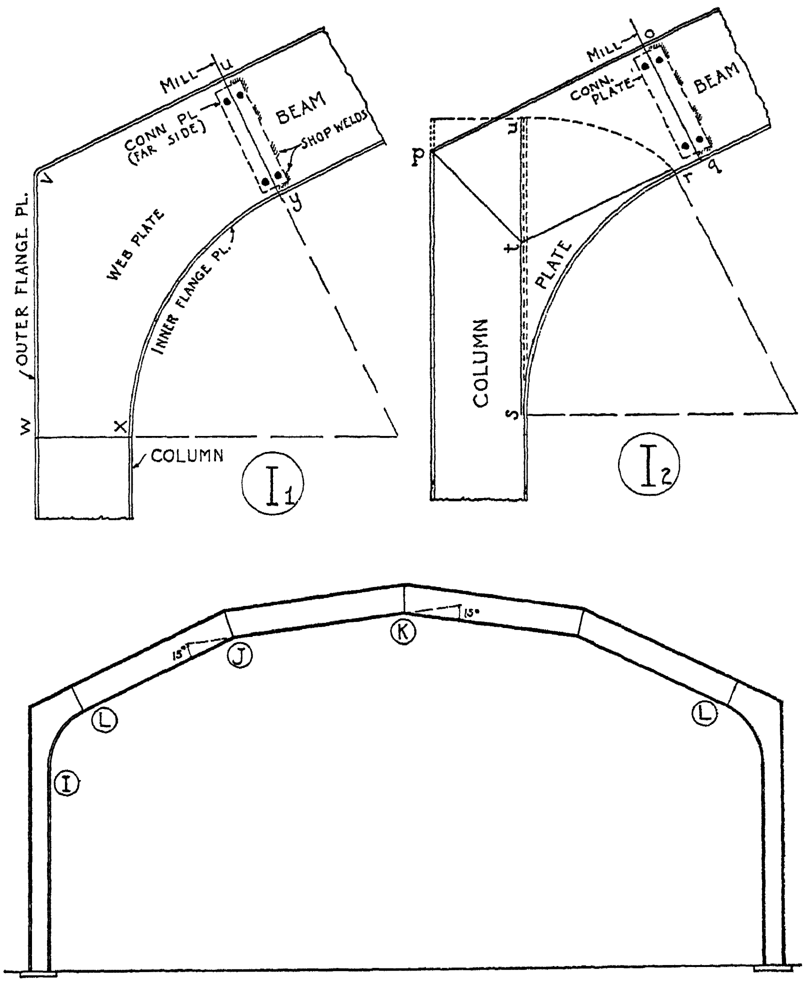


Fig. 918.

column flanges at "w" and at "x" respectively. The field connection is made on line "u y" as shown.

The other method of fabrication is shown at "I-2". In this arrangement, the connecting element between the beam and the column is a short section "o p" of the beam itself from which a section of the bottom flange "r t" has been removed. The left end of the beam is cut along line "p t". The column line is cut along line "s t u" and bent from point "s" so that point "s" rotates to point "r" where it is shop-welded to the bottom flange of beam section "o p".

The outer column flange is cut across along line "p"; the web is cut along line "p t" and shop-welded to the end of beam "o p" on line "pt". A triangular plate "str" with a curved bottom edge is

inserted to close the gap and shop-welded to the column along lines "s t" and "s r", also to the beam web along line "t r".

The field connection is made, first by a pair of bolted web plates. In Fig. 917, detail "G", no bending is intended to be resisted. This condition can be effected by proper location of the end of the cantilever beam and by a suitable relation between the moment of inertia of the cantilever and of the suspended beams resulting in the same slope of both beams at their junction. Under those conditions, only web splicing is needed at points "G". In Fig. 918, at points "L", a large bending moment usually has to be resisted. Consequently, after the structure has been plumbed, not only are the web connection plates field-welded but the flanges are also field-welded together forming a rigid connection.

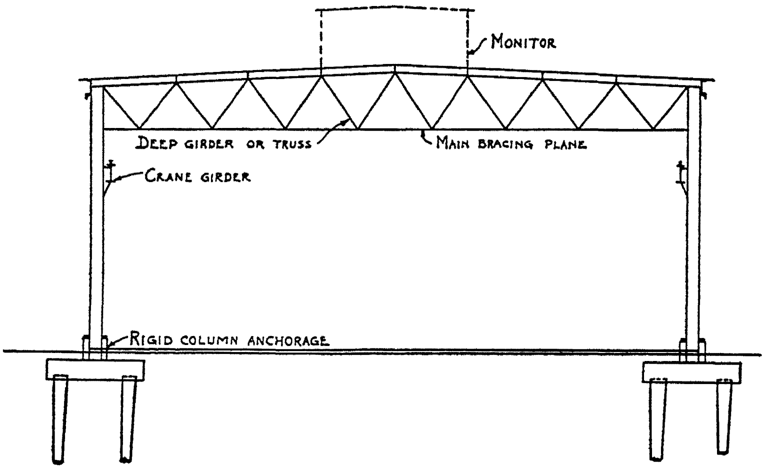


Fig. 919.

Two principal factors affect the choice of the frame for a given structure: the first is the shape of the roof outline; the second is the amount of rigidity to be built into the base of the columns.

(1) Roof outline: Light is a prime requisite in practically any building. It is universally recognized that, in factories, the efficiency of the men is much reduced in poor light. Any wide structure requires a roof outline which admits light through the roof. The amount of glass provided for light through the roof should be somewhere between 20% and 30% of the floor area beneath.

Craneways require a building with great lateral rigidity. The top of the columns carrying the crane girders should be connected by deep horizontal members (Fig. 919). If the craneways are wide or if they are flanked by other buildings that cut out the wall lighting, light access through the roof may be provided either by means of a monitor (dotted outline, Fig. 919), or by a "high-low" roof, a longitudinal section of which is shown in Fig. 920.

The capacity of the cranes in the building is not a big factor in the rigidity requirements: the fast operating of the light cranes makes them

substantially equivalent to heavy, slow operating cranes from the point of view of wear and tear on the structure.

Buildings in which the operations require a vast array of trolleys and conveyors covering most of the plant space, require horizontal main members at the top of the supporting columns to facilitate the hanging and bracing of the trolleys and conveyors. The horizontal members, however, must be placed at a sufficient height above the floor to provide ample room below the conveyors and the objects they carry.

Very often conveyors are required only in certain restricted areas or a scattering of conveyors is needed in more or less permanent areas and positions. Unobstructed headroom is wanted for high machines or for equipment suspended from the roof structure itself. For such cases, trussed structures, either with monitors or of the "high-low" type are ill adapted. Sawtooth construction without trusses (Fig. 901), or monitor frames, (Figs. 903, 906, 907), are well suited to those conditions. For plants or parts of plants in which ventilation is important, a high arch type frame (Fig. 904, Fig. 918), is often advantageous.

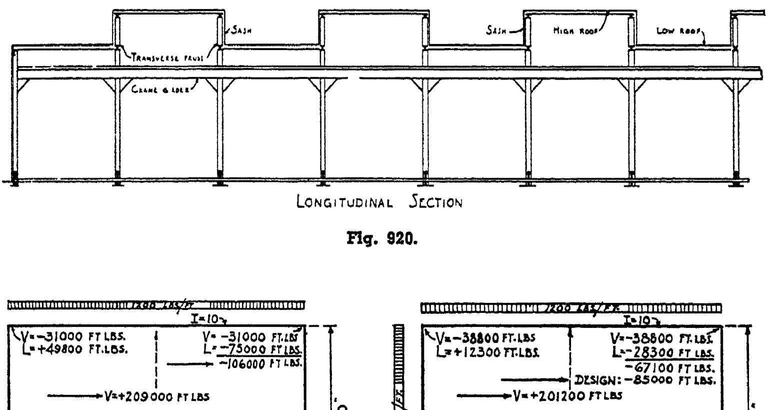


Fig. 920.

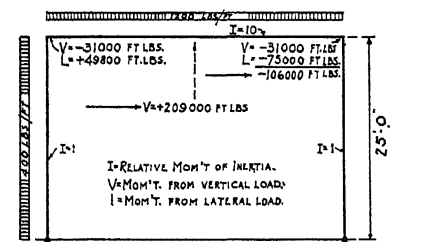


Fig. 921.

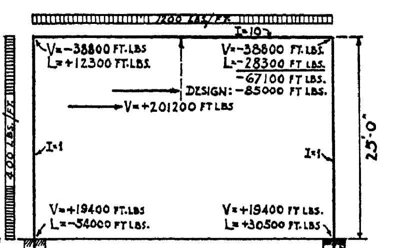


Fig. 922.

Louvres are installed at the peak of the arches, and the high sidewall ventilation together with the louvres provide the required air circulation.

(2) Rigidity of column base: The purpose of rigid column base connections is to save maintenance costs. There is evidently no reason for anchoring column bases relatively to ordinary vertical loading. Structures subject to severe lateral loads such as craneways, also high narrow buildings, should be fixed (anchored rigidly) at the column bases in order to eliminate future costs from cracked or broken glass, leakage, wear and tear on the frame's connections, on the craneways and on the

cranes themselves; trouble from shifting crane track gauge, etc. Of course, if columns are fixed to the foundations, the foundations have to resist the moments induced by the anchorage provided; hence, the cost of the foundations is materially enhanced. It follows that only cases really requiring rigid base connections should be so designed and built.

Figs. 921 and 922 provide a comparison of moments between two horizontal-top frames, one hinged, the other rigidly fixed at the column bases. The vertical loading used is 1200 lbs. per running foot; the lateral load is taken at 400 lbs. per foot of elevation. A 10 to 1 stiffness ratio, common for this type of frame, is assumed—that is, the moment of inertia of the horizontal members is ten times that of the supporting columns. The members of the frames must be able to develop the individual moments shown and also the algebraic sum of such moments at the various joints. The solid arrows point to the moments that govern the design of the members.

The horizontal members must be able to handle a little more than 200,000 foot pounds midway between the columns. Assuming that the lateral load can act either on the left column as shown or on the right column in the opposite direction, the connection of the horizontal member to each column must be made for 106,000 ft. lbs., in Fig. 921. In Fig. 922, the corresponding moment is given as 67,100 ft. lbs., but designers usually arbitrarily increase the beam to column connection capacity in the case of fixed base calculations. The reason is that loose anchor bolts or uneven settling of foundations can readily increase the figured moments. Therefore, instead of providing a connection for 67,100 ft. lbs., the design is made to develop 85,000 ft. lbs.

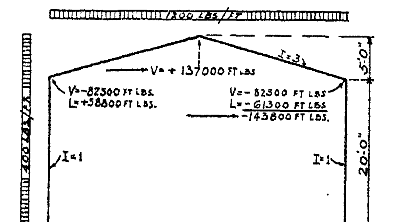


Fig. 923.

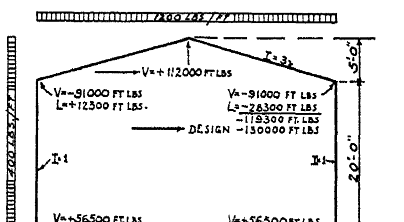


Fig. 924.

Figs. 923 and 924 give a moment comparison for two gable frames, one hinged, the other fully fixed at the column bases. The loading used is the same as that used in Figs. 921 and 922; the stiffness ratio, in this case, is 3 to 1. The solid arrows indicate the moments affecting the design of the members.

In planning a building, it is essential to select a type of frame that is suitable for the purposes of the structure and one that will minimize subsequent maintenance costs. Rigid base connections of columns decrease the stresses to be resisted by the structure, as shown above. The structural elements, however, are usually reduced correspondingly. Flexi-

bility of the joints is a major contributing element to maintenance costs. It is therefore important, whether the structure be anchored to the foundations or not, to provide connections and joints of the most rigid type possible. These can best be secured by arc welded construction which makes each frame one single piece.

CALCULATION OF WELDED FRAMES

Structures belong to either one of two classes:
Group 1 — Determinate structures.
Group 2 — Redundant structures.
Rigid welded frames belong to Group 2 structures.

A redundant structure is one for which all the external reactions cannot be found by the three equations of statics, viz.,

(1) Sum of the horizontal forces = 0.
(2) Sum of the vertical forces = 0.
(3) Sum of the moments about any point = 0.

A redundant structure differs from a determinate structure in having one or more redundant conditions without which the structure would still remain in equilibrium. Such redundant conditions may be members, forces, or moments. In welded frames, the redundants are either forces or moments.

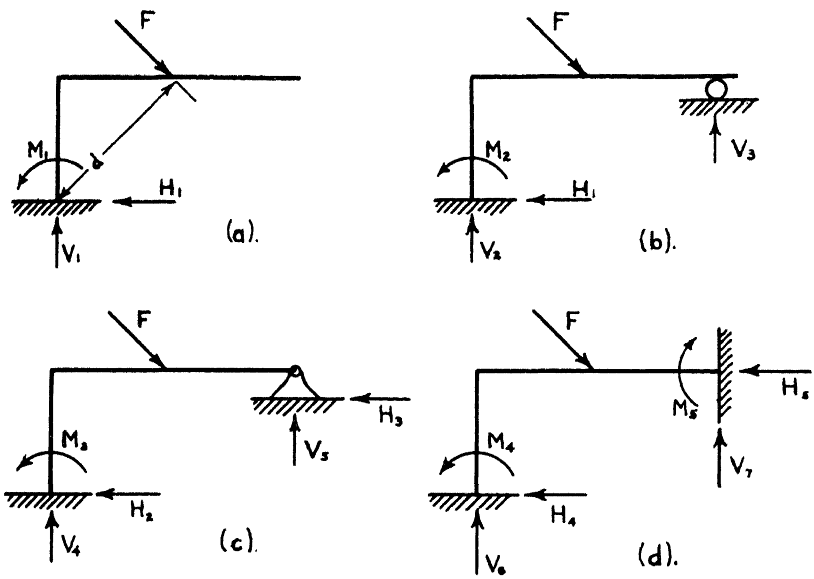


Fig. 925.

The frame shown in Fig. 925-a is a determinate structure: all the conditions of reaction may be found by the three equations of statics mentioned above. The horizontal component of F is equal to H^1, ($\Sigma H = 0$); the vertical component of F is equal to V^1, ($\Sigma V = 0$); the moment Fd is equal to M^1, ($\Sigma M = 0$).

The frame shown in Fig. 925-b has one redundant reaction. The right end is supported by a roller capable of vertical loading only. There are now four unknown reactions: V^2, H^1, M^2, V^3. The three equations of statics are insufficient to calculate these values. A fourth equation is required. This is called an equation of "condition" or of "elasticity."

When the right end of the frame is supported by a hinge which offers resistance in any direction but which has no resistance to rotation, (Fig. 925-c), there are two redundant reactions, since there are five unknows, V^4, V^5, H^2, H^3, M^3. The solution is obtained from the three equations of statics plus two equations of elasticity.

If the right end be fixed, that is, restrained from any motion or rotation, there are six unknowns, V^6, V^7, H^4, H^5, M^4, M^5. This is shown in Fig. 925-d. The solution now requires the three equations of statics plus three equations of conditions.

Welded frames in common use may be divided into two classes according to the way their ends are constructed:

Class (a) — Hinged frames — the ends are free to rotate.

Class (b) — Fixed frames — the ends are unable to rotate.

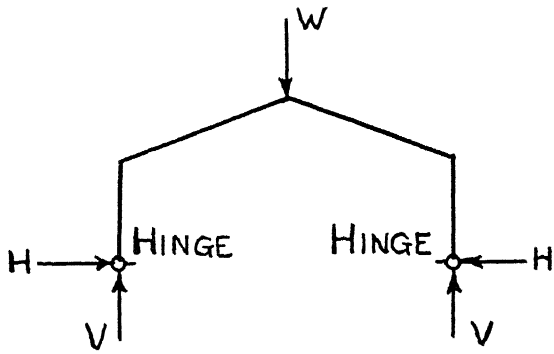


Fig. 926.

An example of frames of class (a) is shown in Fig. 926. There is no moment at the hinged ends, since they are free to rotate. Two equations of statics, $\Sigma V = 0$ and $\Sigma M = 0$, are used to determine the vertical reactions. The third equation of statics, $\Sigma H = 0$, shows that the two horizontal reactions are equal, but it does not determine their magnitude. One equation of elasticity is required to find the magnitude of H.

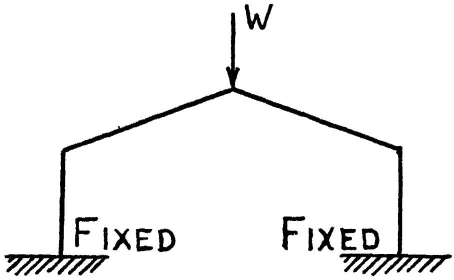


Fig. 927.

Frames of class (b) are exemplified in Fig. 927. Here the ends are fixed, each end being capable of taking a moment. There are now six unknowns, the vertical force, horizontal force, and the moment at each end. The three equations of statics and three equations of elasticity, when solved together simultaneously, will give the value of these unknowns.

After the values of these redundant reactions have been found, the moments and shears of all parts of the frame are calculated just as in the case of a simple beam. From the moments and shears, the size of the members is established, as also the proper welding of the joints of the frame.

The principal types of welded frames in current use are shown in Fig. 928. Various combinations of these outlines are used to provide structures best adapted to each individual case.

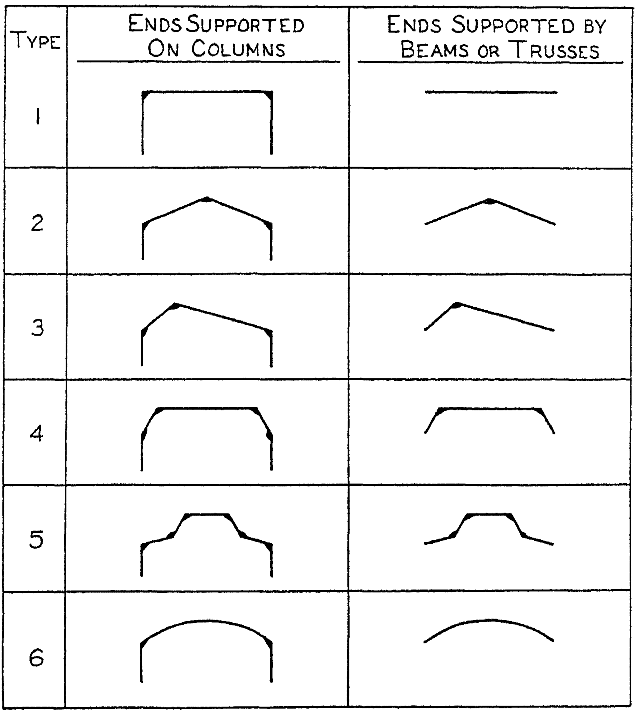


Fig. 928.

A method of calculating the values of the redundants is as follows. Hinged structures are first considered.

Fig. 929 shows a welded frame consisting of two columns having a moment of inertia I_1 and hinged at their bases, together with a transverse beam, having a moment of inertia I_2, welded to the column tops. This structure is loaded by a single vertical load as shown.

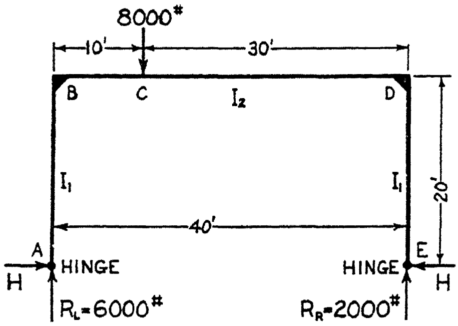


Fig. 929.

The solution of this frame is as follows:

First, consider that the given frame, shown in Fig. 929, is supported, Fig. 930, on a hinge at A, on a roller at E and that it is loaded with the given load of Fig. 929.

Draw the moment diagram for Fig. 930. This is shown in Fig. 932. Call this diagram the M_0 diagram. The value of the moment from A to B is zero. From B to C the moment value rises from zero to 60,000;

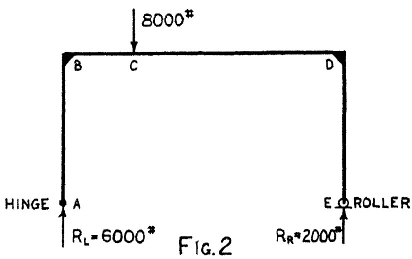


Fig. 930.

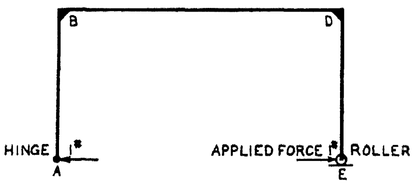


Fig. 931.

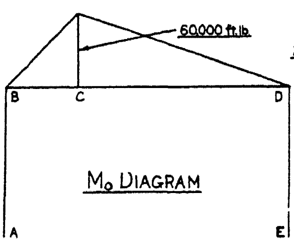


Fig. 932.

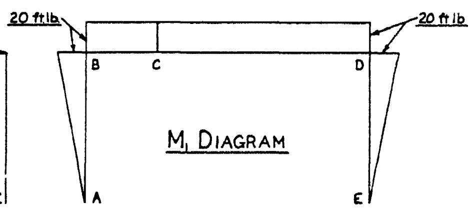


Fig. 933.

from C to D it decreases from 60,000 to zero. From D to E it is zero.

Second, consider, Fig. 931, that the given frame shown in Fig. 929 is supported on a hinge at A, on a roller at E and that it is loaded with a force of one lb. acting in the opposite direction to the reaction H,

and no other forces. For this condition, the reaction of the hinge is evidently equal and opposite to the load.

Draw a moment diagram for Fig. 931. This is shown in Fig. 933. Call this the M_1 diagram. The value of the moment from A to B rises from zero to 20 ft. lbs. From B to D it remains at a constant value, 20 ft. lbs. From D to E it decreases from 20 to zero.

The frame (Fig. 929) belongs to the class shown in Fig. 926; it therefore requires, to establish the value of H, one equation of elasticity. The equation is this:

$$H = \frac{R}{S}, \text{ where } R = \int_A^E \frac{M_0 M_1\, dx}{I}, \text{ and } S = \int_A^E \frac{M_1{}^2\, dx}{I}.$$

Translating the equation into words, the meaning is this: The value of the numerator R is equal to the summation from point A around to point E of the product of all successive values of the M_0 diagram (Fig. 932) by the corresponding values of the M_1 diagram (Fig. 933), each product multiplied by an infinitesimal length dx measured along the line ABCDE, the whole divided by the moment of inertia of that part of the structure which is being summed up (I_1 if the columns are being summed up, I_2 if the top transverse beam is being summed up).

The word *corresponding* means *at the same point in the structure.* For instance, at the middle of the left hand column, the value of the moment in the M_1 diagram is zero. At the same point, the value of the moment in the M_1 diagram is 10. These values, zero and 10, are *corresponding* values. At point C, in the M_0 diagram the moment value is 60,000; at the *same* point in the M_1 diagram, the value is 20. 60,000 and 20 are *corresponding* values.

The value of denominator S is equal to the summation from A around to E of the square of all successive values of the M_1 diagram (Fig. 933), each product multiplied by an infinitesimal length dx measured along the line ABCDE, the whole divided by the moment of inertia of that part of the structure which is being summed up.

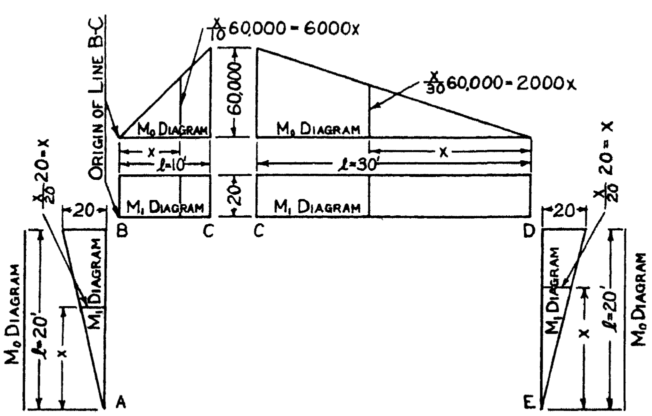


Fig. 934.

Numerator (R)—Fig. 934 shows the segments AB, BC, CD, DE, of M_0 and of the M_1 diagrams drawn alongside each other. From A to B and from E to D, the moment values of the M_1 diagram increase from zero to 20 ft. lb.; all the corresponding M_0 values are zero all the way. Evidently if we sum up the multiplications of all the successive values of the M_1 diagram values by the corresponding values of M_0 which are all zero, the answer of the summation is zero. Thus we see that whenever, in corresponding segments of a welded frame, one or both the moment values of the M_0 or M_1 diagrams is zero, the amount of that part of the diagrams contributed to the value of H is zero.

From B to C, the M_0 values increase from zero to 60,000; the corresponding M_1 values are 20 all the way. The sum of the products of corresponding M_0 and M_1 values from B to C divided by the moment of inertia of the segment BC is evidently the integration between the limits B and C of all the products of the successive values of the M_0 diagram multiplied by all the corresponding values of the M_1 diagram, times dx and divided by the moment of inertia of segment BC, as stated in the formula by the symbol $\int_B^C \frac{M_0 M_1\, dx}{I_2}$

The integrals involved in these calculations are so simple that even a person who has not studied calculus can perform them readily. It is sufficient to know that $\int_0^l x^n dx = \frac{l^{n+1}}{n+1}$. For instance, $\int_0^l x^2 dx = \frac{l^3}{3}$; $\int_0^l x\, dx = \frac{l^2}{2}$; $\int_0^l dx = l$.

Bearing this in mind, considering the segment BC, Fig. 934, the value of the M_0 moment at C is known to be 60,000 ft. lbs. If an origin (i.e. a beginning of length) is assumed at point B, the value of the moment at any point, distant x from point B, from similar triangles, is $\frac{x}{10} 60{,}000 = 6000x$. The value of the M_1 moment at that same point is 20, since M_1 is constant from B to C.

Multiplying these two expressions of M_0 and M_1 times dx and dividing by the moment of inertia of segment BC which we are summing up at this moment, we get $\frac{20\,(6000x\, dx)}{I_2} = \frac{120{,}000x\, dx}{I_2}$. If we call l the distance from B to C, we now integrate the product between the limits zero and l. The expression is written thus: $\int_0^l \frac{120{,}000x\, dx}{I_2}$. I_2 and 120,000 are constants. Constants do not integrate; therefore they are to be written in front of the integral sign, thus: $\frac{120{,}000}{I_2}\int_0^l x\, dx$. The value of $\int_0^l x\, dx$ was stated above to be $\frac{l^2}{2}$. The value of the above

integration is therefore $\frac{120,000}{I_2} \times \frac{l^2}{2}$, where $l = 10$ ft. Substituting this value of l, we get as the value of the integration, $\frac{120,000}{I_2} \times \frac{100}{2} = \frac{6,000,000}{I_2}$.

Considering now segment CD, Fig. 934, the value of the M_0 moment at C is known to be 60,000 ft. lb. By similar triangles the value of the moment at any point between C and D is $\frac{x}{30} 60,000 = 2000x$. The corresponding value of the M_1 moment is 20. Multiplying these two expressions of M_0 and M_1 at any point between C and D times dx, and dividing by I_2, the moment of inertia of the top transverse beam, we get $\frac{40,000\,x\,dx}{I_2}$. This time designating by l the distance from C to D, we integrate this product between the limits 0 and l, thus, $\int_0^l \frac{40,000x\,dx}{I_2}$. Placing the constants in front of the integral sign, the expression becomes $\frac{40,000}{I_2} \int_0^l x\,dx$. Applying the integration formula given above, we get as the value of the integration, $\frac{40,000}{I_2} \times \frac{l^2}{2}$. Substituting the value of l, (30 ft.), we get, $\frac{40,000}{I_2} \times \frac{900}{2} = \frac{18,000,000}{I_2}$.

Denominator (S)—From A to B, and from E to D, Fig. 935, the moment values increase from 0 to 20. From similar triangles the value of the moment at any point distant x from either A or E is $\frac{x}{20} 20 = x$, in each diagram. Squaring this general value, the result is x^2. Calling l the distance from A to B or E to D, and introducing the moment of inertia of these sections, which is I_1 (moment of inertia of the columns),

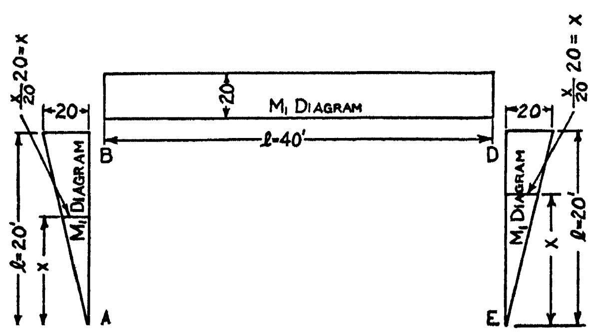


Fig. 935

we get $\int_0^l \frac{x^2dx}{I_1}$. Performing the integration following the rules given above, we get $\frac{l^3}{3I_1}$. Substituting the value of l, we get as the value of the integration $\frac{8000}{3I_1}$.

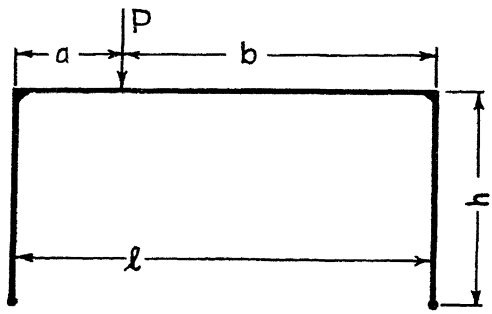


Fig. 936.

Between B and D the value of M_1 at any point is 20. Squaring this value, calling l the length $B-D=40$, and introducing the moment of inertia of the transverse beam with which we are now concerned, we have $\int_0^l \frac{400dx}{I_2}$. Writing the constants in front of the integral sign the expression becomes $\frac{400}{I_2}\int_0^l dx$. Integrating the expression as hereinbefore outlined and substituting the value of l, the result is $\frac{16,000}{I_2}$.

We may now write the summation of the partial integrations as follows,

$$H=\frac{R}{S}=\frac{0+\frac{6,000,000}{I_2}+\frac{18,000,000}{I_2}+0}{\frac{8000}{3I_1}+\frac{16,000}{I_2}+\frac{8000}{3I_1}}=\frac{\frac{24,000,000}{I_2}}{\frac{5333}{I_1}+\frac{16,000}{I_2}}$$

This may be written also in this form:

$$H=\frac{24,000,000}{5333\frac{I_2}{I_1}+16,000}\text{ lbs.}=\frac{7,200,000}{1600\frac{I_2}{I_1}+4800}\text{lbs.}$$

If, instead of the numerical dimensions used in this example, we had used letters, as shown in Fig. 936, then the method we have outlined would have given us the formula:

$$H = \frac{\dfrac{Pabh}{2I_2}}{\dfrac{2h^3}{3I_1} + \dfrac{h^2 l}{I_2}} = \frac{3\,Pab}{4h^2 \dfrac{I_2}{I_1} + 6hl.}$$

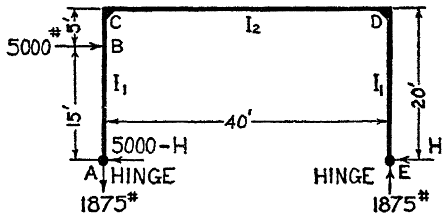


Fig. 937.

Fig. 937 shows the same welded frame which was figured for a vertical load in Figs. 929 to 936 incl., this time loaded with a single horizontal load. As before, it consists of two columns having a moment of inertia I_1, hinged at their bases, and a transverse beam welded to the column tops and having a moment of inertia I_2.

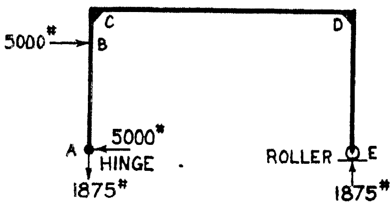


Fig. 938.

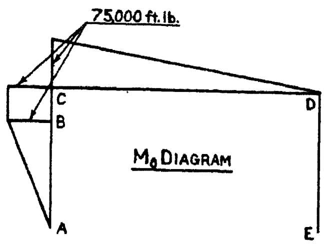


Fig. 939.

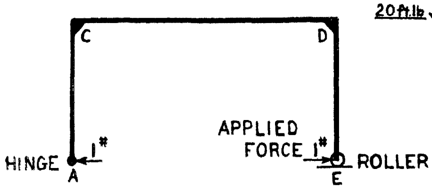


Fig. 940.

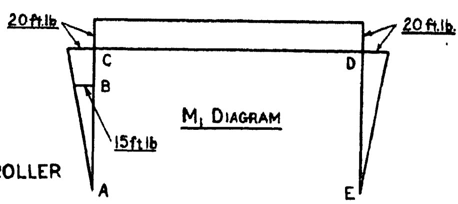


Fig. 941.

Proceeding with the solution of this frame, consider first that the frame is supported on a hinge at A and a roller at E (Fig. 938) and that the given load of Fig. 937 is applied.

Draw a moment diagram for Fig. 938, as shown in Fig. 939. Call this the M_0 diagram. The value of the moment increases from zero at A to 75,000 ft. lbs. at B. From B to C it remains constant at 75,000, and from C to D it decreases to zero. From D to E the moment value is zero.

Next, consider that the given frame is supported on a hinge at A and a roller at E, and that it is loaded with a force of one pound acting in the opposite direction to the reaction H, and no other force. This condition is shown in Fig. 940.

Draw a moment diagram for Fig. 940, as shown in Fig. 941. Call this the M_1 diagram. Observe that this is the same as the M_1 diagram used for the vertical loading in Pages 674 to 678. In fact, *this same M_1 diagram is used for any type of loading on a frame of this shape and size.*

Solution—

$$H = \frac{R}{S} \text{ where } R = \int_A^E \frac{M_0 M_1 \, dx}{I}, \text{ and } S = \int_A^E \frac{M_1^2 dx}{I}.$$

$$R_{AB} = \int_0^l \frac{M_0 M_1 \, dx}{I} = \frac{1}{I_1}\int_0^{15} 5000x^2 dx = \frac{5000\ (15)^3}{3I_1} = \frac{5,625,000}{I_1}$$

$$R_{BC} = \int_0^l \frac{M_0 M_1 \, dx}{I} = \frac{1}{I_1}\int_0^{5} 75000\ (15 + x)\ dx$$

$$= \frac{75000}{I_1}\left(15 \times 5 + \frac{25}{2}\right) = \frac{6,560,000}{I_1},$$

$$R_{CD} = \int_0^l \frac{M_0 M_1 \, dx}{I} = \frac{1}{I_2}\int_0^{40} 20(1875x)\, dx$$

$$= \frac{20 \times 1875}{I_2} \times \frac{40^2}{2} = \frac{30,000,000}{I_2}$$

$$R_{DE} = \int_0^l \frac{M_0 M_1 \, dx}{I} = 0$$

$$R_{AE} = \frac{12,185,000}{I_1} + \frac{30,000,000}{I_2}$$

$$S_{AC} = \int_0^l \frac{M_1^2 dx}{I} = \frac{1}{I_1}\int_0^{20} x^2 dx = \frac{(20)^3}{3I_1} = \frac{8000}{3I_1}$$

$$S_{CD} = \int_0^l \frac{M_1^2 dx}{I} = \frac{1}{I_2}\int_0^{40} (20)^2 dx = \frac{16,000}{I_2},$$

$$S_{DE} = S_{AC} = \frac{8000}{3I_1},$$

$$S_{AE} = \frac{5333}{I_1} + \frac{16,000}{I_2};$$

$$H = \frac{\frac{12,185,000}{I_1} + \frac{30,000,000}{I_2}}{\frac{5333}{I_1} + \frac{16,000}{I_2}}$$

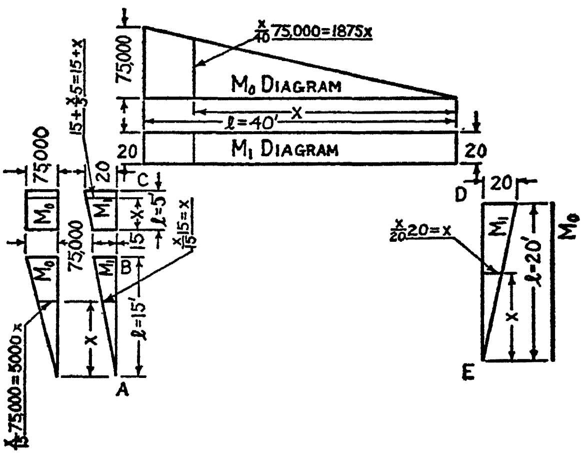


Fig. 942

Explanation—Fig. 942 shows the corresponding segments of the M_0 and M_1 moment diagrams drawn alongside each other. From A to B the M_0 values increase from zero to 75,000. If an origin is assumed at point A, then the value of the M_0 moment at any point between A and B is, from similar triangles, $\frac{x}{15}$ (75,000) = 5000x. Similarly, the value of the M_1 moment at any point between A and B is $\frac{x}{15}\,15 = x$. Substituting these values into the formula for R,

$$R_{AB} = \int_0^l \frac{M_0 M_1\,dx}{I} = \int_0^l \frac{(5000x)\ (x)\,dx}{I_1} = \frac{5000}{I_1}\int_0^l x^2\,dx.$$

Remembering that $\int_0^l x^2\,dx = \frac{l^3}{3}$, we get on integrating,

$$R_{AB} = \frac{5000 l^3}{I_1\ 3},\ \text{and since } l = 15,\ R_{AB} = \frac{5,625,000}{I_1}.$$

Between B and C the M_0 moment values remain constant at 75,000 while the M_1 values vary from 15 at B to 20 at C. The expression for the M_1 value at any point between B and C is obtained by referring to

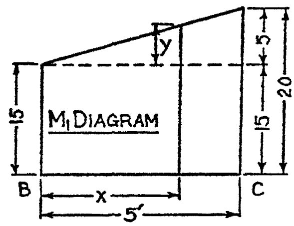


Fig. 943.

Fig. 943. The diagram may be divided into a rectangle and a triangle as shown. Then the value at any point is $(15 + y)$. From similar triangles, $y = \frac{x}{5}\,5 = x$, so that the M_1 value between B and C is $(15 + x)$. Substituting these values in the formula for R,

$$R_{BC} = \int_0^l \frac{M_0 M_1\, dx}{I} = \int_0^l \frac{(75{,}000)\,(15 + x)\,dx}{I_1}$$

$$= \frac{75{,}000}{I_1}\left[\int_0^l 15dx + \int_0^l x\,dx\right].$$

Since $\int_0^l dx = l$, and $\int_0^l x\,dx = \frac{l^2}{2}$, we have:

$$R_{BC} = \frac{75{,}000}{I_1}\left[15\,l + \frac{l^2}{2}\right].$$ Substituting the value of l,

$$R_{BC} = \frac{75{,}000}{I_1}\left(15\cdot 5 + \frac{25}{2}\right) = \frac{6{,}560{,}000}{I_1}.$$

Between C and D the M_0 moment values decrease from 75,000 at C to zero at D. The M_1 values remain constant at 20 over this segment. From similar triangles the value of the M_0 moment at any point between C and D is $\frac{x}{40}\,75{,}000 = 1875x$. Substituting these values in the formula for R,

$$R_{CD} = \int_0^l \frac{M_0 M_1\, dx}{I} = \int_0^l \frac{(1875x)\,(20)\,dx}{I_2} = \frac{(1875)\,20}{I_2}\int_0^l x dx.$$

Integrating this expression and substituting the value of l, we have,

$$R_{CD} = \frac{37{,}500}{I_2}\,\frac{l^2}{2} = \frac{37{,}500}{I_2}\,\frac{(40)^2}{2} = \frac{30{,}000{,}000}{I_2}$$

Between D and E the M_0 moment values are zero, hence the value of R for this segment is also zero, as explained on Page 674.

Adding the various segments,

$$R = R_{AB} + R_{BC} + R_{CD} + R_{DE}$$

$$= \frac{5,625,000}{I_1} + \frac{6,562,000}{I_1} + \frac{30,000,000}{I_2} + 0;$$

$$= \frac{12,187,000}{I_1} + \frac{30,000,000}{I_2}$$

It has been noted above that the M_1 diagram used in this example is identical with the M_1 diagram used in the example of Fig. 933. Therefore the value of $S = \int \frac{M_1{}^2 dx}{I}$ will be the same for both types of loading and we use the value of S computed on Page 674. Then,

$$S = \frac{5333}{I_1} + \frac{16,000}{I_2}.$$

Dividing R by S, we have,

$$H = \frac{R}{S} = \frac{\dfrac{12,185,000}{I_1} + \dfrac{30,000,000}{I_2}}{\dfrac{5333}{I_1} + \dfrac{16,000}{I_2}}$$

$$= \frac{12,185,000\dfrac{I_2}{I_1} + 30,000,000}{5333\dfrac{I_2}{I_1} + 16,000}$$

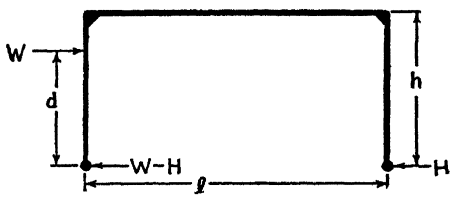


Fig. 944.

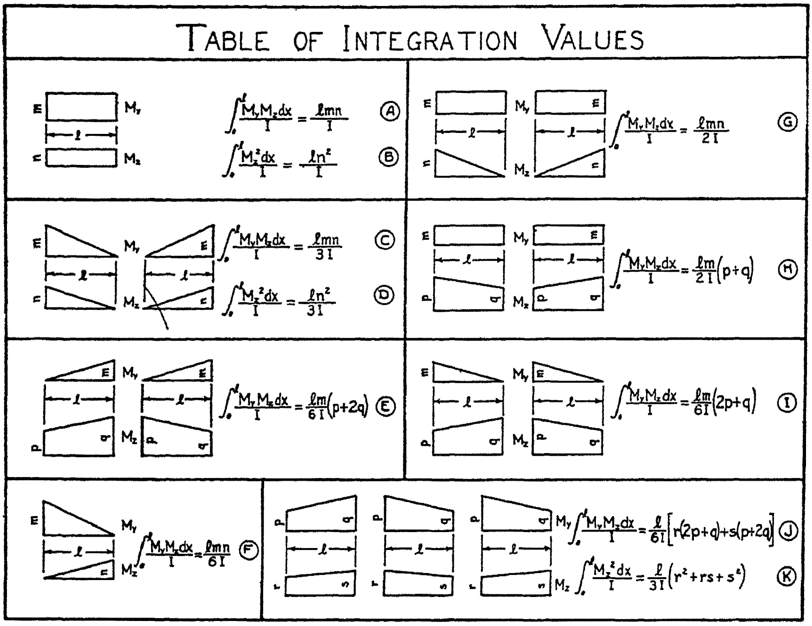
If letters were used in place of the numerical dimensions as shown in Fig. 944, the method outlined would result in the formula:

$$H = Wd \left[\frac{h^2 - \dfrac{d^2}{3} + hl\dfrac{I_1}{I_2}}{2h^2\left(\dfrac{2}{3}h + l\dfrac{I_1}{I_2}\right)} \right]$$

A study of Pages 674 to 683 shows that the process of finding the value of R consists of integrating together successively the corresponding segments of the M_0 and of the M_1 diagrams and adding the results together. To find the value of S, we integrate successively each segment

of the M_1 diagram with itself and add the results together.

The various segments of the M_0 or of the M_1 diagrams consist, for concentrated loads, of rectangles, triangles, and trapezoids. Therefore, to obtain the value of R, integrating together the corresponding segments



of the M_0 and of the M_1 diagram consists in integrating together pairs of such figures, that is, two triangles or a triangle and a rectangle, or a rectangle and a trapezoid or two trapezoids, etc.

To obtain the value of S, integrating each segment of the M_1 diagram with itself consists in integrating a triangle with the same triangle,

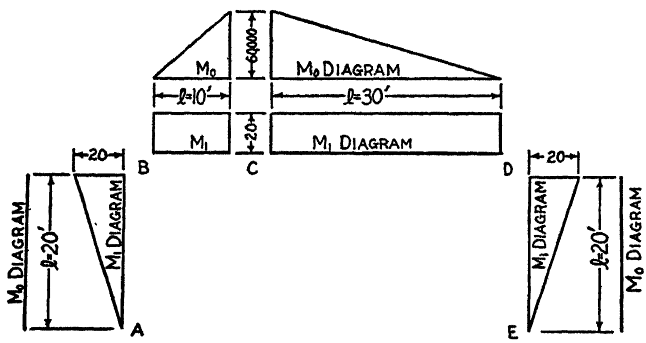


Fig. 945.

or a trapezoid with the same trapezoid or a rectangle with the same rectangle.

The table above gives the *values* of all such figures integrated together. Using the table eliminates the integration work and permits finding the values of R and S much more rapidly.

To illustrate its use, the solution of the problem shown in Fig. 929, is now accomplished with the help of the table.

Numerator (R) — Referring to Fig. 945 (which is similar to Fig. 934), the integration of triangle AB of the M_1 diagram with the corresponding segment of the M_0 diagram is zero, since the M_0 diagram is a line, not an area. Considering next segment BC, we have a triangle of the M_0 diagram to integrate with a rectangle of the M_1 diagram. The table, Formula G, gives as the integration value for this combination, $\frac{lmn}{2\,I}$. Substituting the values of the symbols, the value is

$$\frac{10 \times 20 \times 60{,}000}{2\,I_2} = \frac{6{,}000{,}000}{I_2}.$$

Next, in section CD, integrate the M_0 triangle with the M_1 rectangle. Again, Formula G gives as the value, $\frac{lmn}{2\,I}$. Substituting the numerical values, we have $\frac{30 \times 20 \times 60{,}000}{2\,I_2} = \frac{18{,}000{,}000}{I_2}$. The integration value of triangle DE of the M_1 diagram and the corresponding M_0 diagram, a line, is again zero.

The value of R is then $\frac{6{,}000{,}000}{I_2} + \frac{18{,}000{,}000}{I_2} = \frac{24{,}000{,}000}{I_2}$ as on Page 674.

Denominator (S). — The operation consists in integrating each segment of the M_1 diagram with itself and adding the results together. Segment AB is a triangle. Formula D gives the value as $\frac{ln^2}{3\,I}$. Substituting the numerical values, Fig. 945, we have, $\frac{20 \times 20^2}{3\,I_1} = \frac{8000}{3\,I_1}$, I_1 being the moment of inertia of the column. Segment BD is a rectangle. Formula B gives the value as $\frac{ln^2}{I} = \frac{40 \times 20^2}{I_2} = \frac{16{,}000}{I_2}$, I_2 being the moment of inertia of the beam. Segment DE is a triangle. Formula D gives the value as $\frac{ln^2}{3\,I} = \frac{20 \times 20^2}{3\,I_1} = \frac{8000}{3\,I_1}$.

Adding the above results we get

$$S = \frac{8000}{3\,I_1} + \frac{16{,}000}{I_2} + \frac{8000}{3\,I_1} = \frac{5333}{I_1} + \frac{16{,}000}{I_2} \text{ as on Page 674.}$$

Note that the table eliminates all actual integrations.

As a further illustration of the use of the table, the solution of the

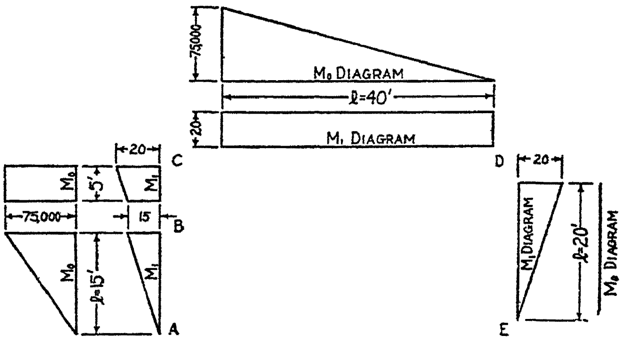


Fig. 946.

problem shown in Fig. 937, is now given. Fig. 946 shows the corresponding segments of the M_0 and M_1 diagrams.

Numerator (R)—

Segment AB—Two Triangles. Value, by Formula C,

$$\frac{lmn}{3\,I} = \frac{15 \times 15 \times 75{,}000}{3\,I_1} = \frac{5{,}625{,}000}{I_1}.$$

Segment BC—Rectangle and Trapezoid. Value, Formula H,

$$\frac{lm}{2\,I}\left(p + q\right) = \frac{5 \times 75{,}000}{2\,I_1}\left(15 + 20\right) = \frac{6{,}560{,}000}{I_1}.$$

Segment CD—Triangle and Rectangle. Value, Formula G,

$$\frac{lmn}{2\,I} = \frac{40 \times 20 \times 75{,}000}{2\,I_2} = \frac{30{,}000{,}000}{I_2}.$$

Segment DE—Zero.

$$\text{Adding, } R_{AE} = \frac{12{,}185{,}000}{I_1} + \frac{30{,}000{,}000}{I_2} \text{ as on Page 679.}$$

Denominator (S)—

Segment AC—Triangle. Value, Formula D,

$$\frac{ln^2}{3\,I} = \frac{20 \times 20^2}{3\,I_1} \quad \frac{2667}{I_1}.$$

Segment CD—Rectangle. Value, Formula B,

$$\frac{ln^2}{I} = \frac{40 \times 20^2}{I_2} = \frac{16{,}000}{I_2}.$$

Segment DE—Triangle. Value, Formula D,

$$\frac{ln^2}{3\,I} = \frac{20 \times 20^2}{3\,I_1} = \frac{2667}{I_1}.$$

$$\text{Adding, } S_{AE} = \frac{5333}{I_1} + \frac{16{,}000}{I_2}.$$

$$\text{Whence, } H = \frac{R}{S} = \frac{\dfrac{12{,}185{,}000}{I_1} + \dfrac{30{,}000{,}000}{I_2}}{\dfrac{5333}{I_1} + \dfrac{16{,}000}{I_2}} \text{ as on Page 679.}$$

The method outlined on Pages 674 to 686 for the solution of the formula $H = \frac{R}{S}$ can readily be used to develop formulae for the value of H. Such formulae are given on Page 691 for single loads, applied in the positions indicated, for some of the frames shown in the second column of the table, Page 673. Values for other frames, are given on Pages 692 to 707.

Position and Direction of H

For vertical loads, the value of H acting at the right hinge is balanced by a force equal to H, acting in the opposite direction at the left hinge. If the vertical load acts downward, the resulting H at the right hinge acts from right to left, and the balancing force at the left hinge acts from left to right. If the vertical force acts upward, the resulting H at the right hinge acts from left to right and the balancing force at the left hinge acts from right to left.

For horizontal loads, the force H is to be applied to the hinge at the opposite end of the frame from the point where the horizontal force is applied. This force H, for a horizontal load P, is balanced at the opposite hinge by a horizontal force P−H. Both forces H and P−H always act in a direction opposite to the direction of horizontal load P.

For crane moments, force H, at the right hinge acts from right to left and is balanced at the left hinge by a force equal to H, acting from left to right. The cranes are assumed to be located under the frame in question and not outside the structure.

Use of the Formulae

To use the formulae,

1. Make a free-hand sketch showing the single load, a hinge at the left end and a roller at the right end if the single load is vertical, exactly as in Fig. 930; if the load is horizontal, show a hinge at the end nearest the load and a roller at opposite end of the frame. Note that, for any load whatever or for a moment applied anywhere to the frame, the roller-end reaction due to that load or moment must always be a vertical reaction — up or down, depending on the direction of the applied load or moment.

2. From the sketch, figure the dimensions and reactions, also the moments at all points marked M_Q, M_B, M_C, . . . , in the table and mark them on the sketch.

3. Substitute dimensions and values of M_Q, M_B, M_C, . . . , in the given formula, obtaining the value of H for the single load shown on the sketch. For frames loaded with several loads, repeat the above operation for each single load, obtaining each time the value of H for each single load successively.

4. Sum up the horizontal forces (values of H or balancing forces) at each hinge, obtaining the total horizontal reactions.

Example

A 40-foot symmetrical hip frame, 10 feet high, is loaded, as shown in Fig. 947, with three horizontal loads, four vertical loads acting

downwards and one vertical load acting upwards. It is desired to find the values of H_L and H_R.

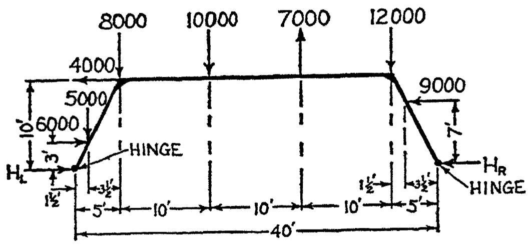
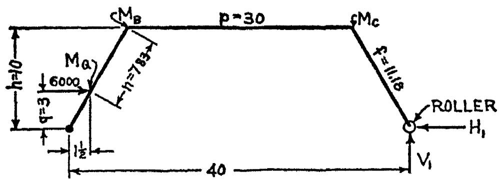


Fig. 947.

Following the directions given above, sketch A is first made showing a single load, the 6000 lbs. horizontal applied on the left slope; a hinge at left end, which is nearest the load; and a roller under the right end, which is the end opposite the point where the horizontal load is applied. The H corresponding to this single 6000 lb. load, which



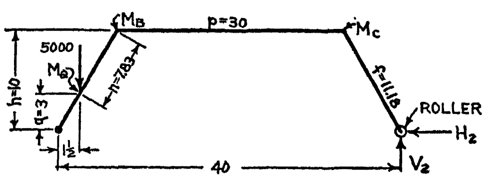
Sketch A

will be called H_1, will now be found. The value of V_1 is $6000 \times \frac{3}{40}$ $= 450$. $M_Q = 450 \times (40 - 1\frac{1}{2}) = 17{,}325$.
$M_B = 450 \times 35 = 15{,}750$,
and $M_C = 450 \times 5 = 2250$. Substituting in formula (6) the values of M_Q, M_B, M_C, and the dimensions noted in sketch A,

$$H_1 = \frac{17{,}325\,(2 \times 11.18 \times 3 + 7.83 \times 10) + 15{,}750\,[10\,(3 \times 30 + 2 \times 7.83) + 7.83 \times 3]}{2 \times 10^2\,(2 \times 11.18 + 3 \times 30)}$$

$$+ \frac{2250}{2 \times 10} = \frac{17{,}325 \times 145.4 + 15{,}750 \times 1080}{22{,}472} + 112 = +980 = H_1,$$

marking with the sign "+" the H's which act from right toward the left.



Sketch B

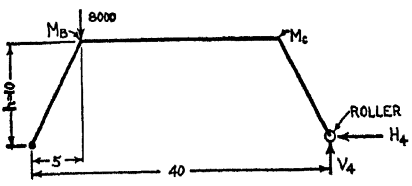
Sketch B is now made, showing the reactions and moments due to the 5000 lb. vertical load applied on the slope, a hinge at the left end, a roller at the right. $V_2 = 5000 \times \frac{1\frac{1}{2}}{40} = 188.$

$M_Q = 188 \times (40 - 1\frac{1}{2}) = 7240$. $M_B = 188 \times 35 = 6560$; $M_C = 188 \times 5 = 940$. Substituting in formula (6) the values of M_Q, M_B, M_C, from sketch B and calling H_2 the value of R resulting from the 5000 lb. vertical load,

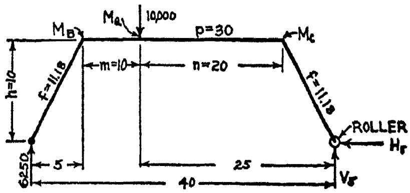
$$H_2 = \frac{7240 \times 145.4 + 6560 \times 1080}{22{,}472} + \frac{940}{20} = +410$$ lb. acting again from right to left.

The 4000 lb. horizontal load acting at the hip requires no sketch: according to the note beneath the formula (5), its value of H, which we will call H_3, is $\frac{4000}{2} = -2000$ lb., acting from left to right in opposition to the 4000 lb. load.

Passing on to the 8000 lb. load on the left hip, draw sketch C.



Sketch C



Sketch D

$V_4 = 8000 \times \frac{5}{40} = 1000$; $M_B = 1000 \times 35 = 35{,}000$; $M_C = 1000 \times 5 = 5000$. By formula (5), $H_4 = \frac{35{,}000 + 5000}{2 \times 10} = +2000$, acting from right to left.

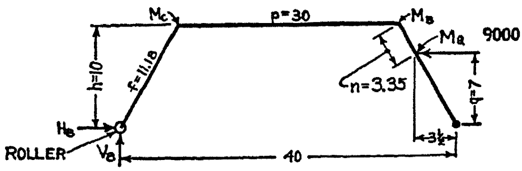
In sketch D, $V_5 = 10{,}000 \times \frac{15}{40} = 3750$. The left reaction is then 6250 lb. $M_B = 6250 \times 5 = 31{,}250$; $M_Q = 3750 \times 25 = 93{,}750$; and $M_C = 3750 \times 5 = 18{,}750$. Substituting in formula (7) the above moments and dimensions of sketch D,

$$H_5 = \frac{31{,}250\,(2 \times 11.18 + 3 \times 10) + 3 \times 30 \times 93{,}750 + 18{,}750\,(2 \times 11.18 + 3 \times 20)}{2247.2}$$

$= +5180$, acting from right to left.

The next load is 7000 lb. acting vertically upward, (see Fig. 947). Being located on the frame symmetrically with the downward 10,000 lb. load, it will give for its value of H, which we will call H_6, an amount $\frac{7000}{10{,}000}$ of H_5 acting opposite to H_5, since the 7000 lb. load is acting up while the 10,000 lb. load acts down. Therefore, $H_6 = -\frac{7}{10} \times 5180 = -3625$ lb. acting from left to right.

The load on the right hip is $1\frac{1}{2}$ times as great as the one on the left hip; both act downward. Therefore the H value for this 12,000 lb. load, which we call H_7, will be one and one-half times H_4, or $H_7 = 2000 \times 1\frac{1}{2} = +3000$.



Sketch E

Finally, draw sketch E for 9000 lb. force on right slope. Roller is at left end, opposite to point of application of load; hinge at right end, which is nearest the load. $V_8 = \frac{9000 \times 7}{40} = 1575$. $M_Q = 1575 \times 36\frac{1}{2} = 57488$. $M_B = 1575 \times 35 = 55{,}125$; $M_C = 1575 \times 5 = 7875$. Substituting in formula (6) the above moments and dimensions of sketch E and giving a negative value to H_8, as it acts from left to right, opposing the 9000 lb. applied load,

$$H_8 = -\left[\frac{57{,}488\,(2 \times 11.18 \times 7 + 3.35 \times 10) + 55{,}125\,[10\,(3 \times 30 + 2 \times 3.35) + 3.35 \times 7]}{22{,}472} + \frac{7875}{2 \times 10}\right] = -\left[\frac{57{,}488 \times 190 + 55{,}125 \times 990.5}{22{,}472} + 394\right]$$

$= -3310$ lb. acting from left to right at left end of the frame.

Fig. 948 shows the values of $H_1, \ldots H_8$ and of the balancing forces at the right and left hinges. Summing up, we find that the horizontal force at the right hinge, which we denote as H_R, necessary to hold all the loads in equilibrium at that hinge, amounts to $+ 255$ lbs., acting from right to left. Similarly, at the left hinge, the horizontal force which we denote as H_L, necessary to hold all the loads and H_R in equilibrium amounts to -7255 lbs., acting from left to right.

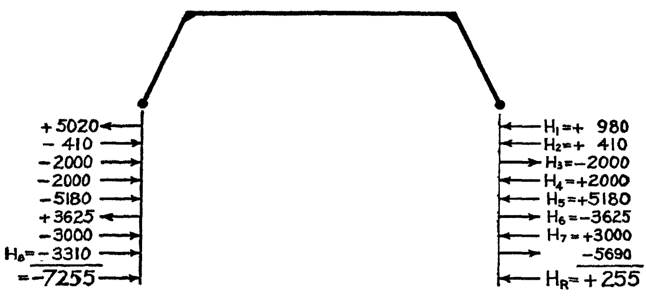
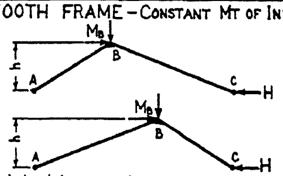


Fig. 948.

Values of H for Hinged Frames

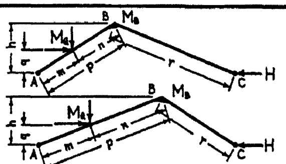
Concentrated Loads

SAWTOOTH FRAME—CONSTANT MT OF INERTIA



Single load, horizontal or vertical, at apex.

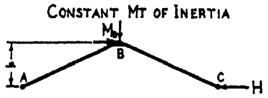
$$H = \frac{M_B}{h} \quad \text{------------} \quad (1)$$



Single load, horizontal or vertical, applied on either slope

$$H = \frac{M_a(2pq+nh)+M_B[2h(n+r)+nq]}{2h^2(p+r)} \quad \text{----} \quad (2)$$

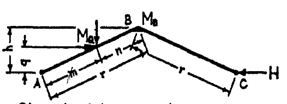
SYMMETRICAL GABLE FRAME
CONSTANT MT OF INERTIA



Single load, horizontal or vertical, at apex

$$H = \frac{M_B}{h} \quad \text{-----------} \quad (3)$$

Note. For horizontal load P at apex, formula (3) reduces to $H = \frac{P}{2}$.



Single load, horizontal or vertical, applied on either slope.

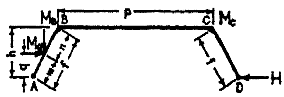
$$H = \frac{M_a(2rq+nh)+M_B[2h(n+r)+nq]}{4rh^2} \quad \text{-----} \quad (4)$$

SYMMETRICAL HIP FRAME
CONSTANT MT. OF INERTIA

Single load, horizontal or vertical, applied at hip.

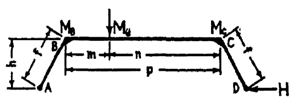
$$H = \frac{M_B+M_C}{2h} \quad \text{------------} \quad (5)$$

Note: For horizontal load P at hip, formula (5) reduces to $H = \frac{P}{2}$.



Single load, horizontal or vertical, applied on frame's sloping side

$$H = \frac{M_a(2fq+nh)+M_B[h(3p+2n)+nq]}{2h^2(2f+3p)} + \frac{M_C}{2h} \quad \text{--} \quad (6)$$



Single vertical load applied between hips.

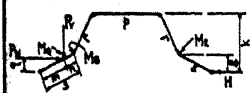
$$H = \frac{M_B(2f+3m)+3pM_a+M_C(2f+3n)}{2h(2f+3p)} \quad \text{----} \quad (7)$$

Values of H for Hinged Frames

Concentrated Loads

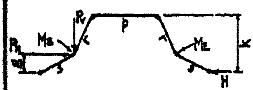
SYMMETRICAL MONITOR FRAME

One moment of inertia.



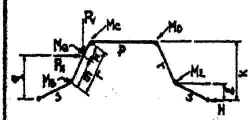
Single vertical or horizontal load on lower slope.

$$H=\frac{M_a(2qs+ng)+M_B[n(2g+q)]+2sgM_E+3(M_B+M_E)[rg+k(p+r)]}{4sg^2+6pk^2+4r(g^2+gk+k^2)} \qquad (8)$$



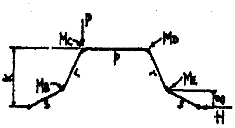
Single vertical or horizontal load at top of lower slope.

$$H=\frac{(M_B+M_E)[g(2s+r)+3k(p+r)]}{4sg^2+6pk^2+4r(g^2+gk+k^2)} \qquad (9)$$



Single vertical or horizontal load on upper slope.

$$H=\frac{M_B[2sg+m(2g+q)]+M_a(2rq+mg+nk)+M_C[3pk+n(2k+q)]+M_D[3pk+r(2k+g)]+M_E[2sg+r(2g+k)]}{4sg^2+6pk^2+4r(g^2+gk+k^2)} \qquad (10)$$

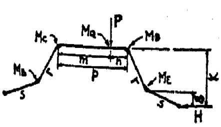


Single vertical load at hip

$$H=\frac{(M_B+M_E)[2g(r+s)+rk]+(M_C+M_D)[rg+k(3p+2r)]}{4sg^2+6pk^2+4r(g^2+gk+k^2)} \qquad (11)$$

Single horizontal load at hip

$$H=\frac{P}{2} \qquad (12)$$



Single vertical load on cross beam.

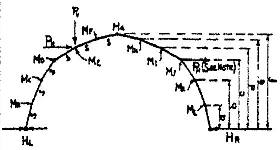
$$H=\frac{(M_B+M_E)[2g(r+s)+rk]+(M_C+M_D)[r(2k+g)]+3k(mM_C+pM_a+nM_D)}{4sg^2+6pk^2+4r(g^2+gk+k^2)} \qquad (13)$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

SYMMETRICAL TWO HINGE ARCH FRAME OF ANY SHAPE

One moment of inertia



ARCH RING DIVIDED INTO TWELVE EQUAL STRAIGHT LINE SEGMENTS

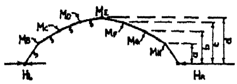
Single vertical or horizontal load at any panel point—i.e. junction of straight line segments

OR

Any number of equal or unequal vertical and/or horizontal loads at some or all panel points applied simultaneously

$$H=\frac{(M_B+M_L)(4a+b)+(M_C+M_K)(a+4b+c)+(M_D+M_J)(b+4c+d)+(M_E+M_I)(c+4d+e)+(M_F+M_H)(d+4e+f)+2M_G(2f+e)}{4(2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+f^2)} \quad (14)$$

Note that for horizontal loads applied to the right half of the arch, the H given by the formula is H_L. See Plate 71, "Position and direction of H"

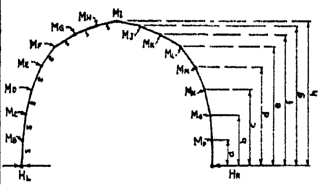


ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGT LINE SEGMENTS LESS THAN TWELVE (8 SHOWN)

Loading as above

Formula (14) above can be used without recalculation by decreasing the number of terms. Thus, for an EIGHT equal straight segment arch, the value of H_R reads:

$$H_R=\frac{(M_B+M_H)(4a+b)+(M_C+M_G)(a+4b+c)+(M_D+M_F)(b+4c+d)+2M_E(2d+c)}{4(2a^2+ab+2b^2+bc+2c^2+cd+d^2)} \quad (15)$$



ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS GREATER THAN TWELVE (16 SHOWN)

Loading as above

Formula (14) above can be used without recalculation by increasing the number of terms. Thus, for a SIXTEEN equal straight segment arch, the value of H_R reads

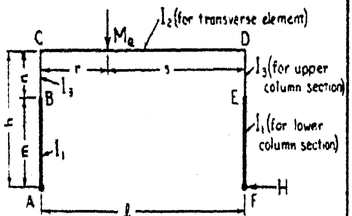
$$H_R=\frac{(M_B+M_P)(4a+b)+(M_C+M_O)(a+4b+c)+(M_D+M_N)(b+4c+d)+(M_E+M_M)(c+4d+e)+(M_F+M_L)(d+4e+f)+(M_G+M_K)(e+4f+g)+(M_H+M_J)(f+4g+h)+2M_I(2h+g)}{4(2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+2f^2+fg+2g^2+gh+h^2)} \quad (16)$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

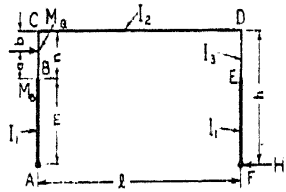
RECTANGULAR BENT

Three Moments of Inertia



Single vertical load applied to transverse element

$$H=\frac{3M_a h\ell}{4m^3\frac{I_2}{I_1}+4n\frac{I_2}{I_3}(m^2+mh+h^2)+6\ell h^2} \quad \text{-- (17)}$$

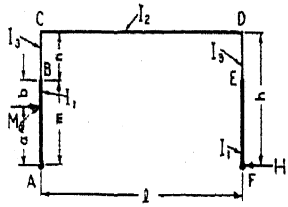


Single horizontal load applied to upper column section

$$H=\frac{M_B\left[2m^2\frac{I_2}{I_1}+a\frac{I_2}{I_3}(3m+a)\right]+M_a\left[3b\frac{I_2}{I_3}(2h-b)+a\frac{I_2}{I_3}(3m+2a)+3\ell h\right]}{4m^3\frac{I_2}{I_1}+4n\frac{I_2}{I_3}(m^2+mh+h^2)+6\ell h^2} \quad \text{---- (20)}$$

NOTE. For single horizontal load P applied at top of upper column section,

$$H=\frac{P}{2} \quad \text{--------- (21)}$$

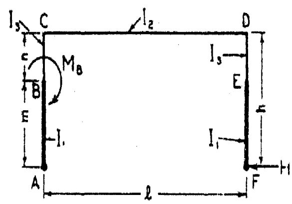


Single horizontal load applied to lower column section

$$H=\frac{3M_a\left[\left(\frac{2a^2}{3}+ab+bm\right)\frac{I_2}{I_1}+n\frac{I_2}{I_3}(m+h)+\ell h\right]}{4m^3\frac{I_2}{I_1}+4n\frac{I_2}{I_3}(m^2+mh+h^2)+6\ell h^2} \quad (18)$$

NOTE. For single horizontal load applied at junction of the two column sections, the above value of H reduces to

$$H=\frac{3M_B\left[\frac{2}{3}m^2\frac{I_2}{I_1}+n\frac{I_2}{I_3}(m+h)+\ell h\right]}{4m^3\frac{I_2}{I_1}+4n\frac{I_2}{I_3}(m^2+mh+h^2)+6\ell h^2} \quad \text{--- (19)}$$



Crane moment applied at junction of lower and upper column sections

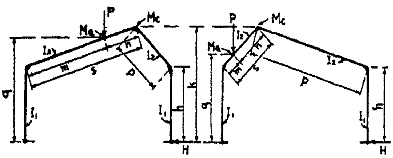
$$H=\frac{3M_B\left[n\frac{I_2}{I_3}(m+h)+\ell h\right]}{4m^3\frac{I_2}{I_1}+4n\frac{I_2}{I_3}(m^2+mh+h^2)+6\ell h^2} \quad \text{-- (22)}$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

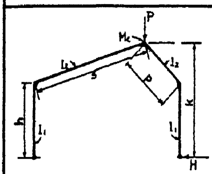
SAWTOOTH BENT

Two moments of inertia



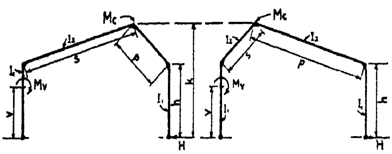
Single vertical load on either slope

$$H=\frac{M_a[m(2q+h)+n(2q+k)]+M_c[n(2k+q)+p(2k+h)]}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (23)$$



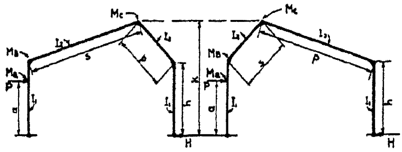
Single vertical load applied at apex

$$H=\frac{M_c(s+p)(2k+h)}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (24)$$



Crane moment applied to either column

$$H=\frac{3M_v\left[(h^2-v^2)\frac{I_2}{I_1}+\frac{s}{3}(2h+k)\right]+M_c(s+p)(2k+h)}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (25)$$

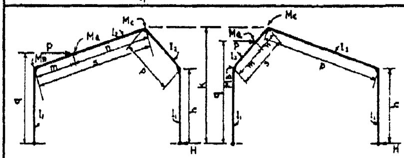


Single horizontal load applied to column

$$H=\frac{M_a\left[(3h^2-a^2)\frac{I_2}{I_1}+s(2h+k)\right]+M_c(s+p)(2k+h)}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (26)$$

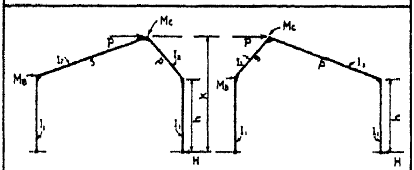
When load P is applied to top of column, formula (26) becomes

$$H=\frac{M_B\left[2h^2\frac{I_2}{I_1}+s(2h+k)\right]+M_c(s+p)(2k+h)}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (27)$$



Single horizontal load applied to either sloping side

$$H=\frac{M_B\left[2h^2\frac{I_2}{I_1}+m(2h+q)\right]+M_a[m(2q+h)+n(2q+k)]+M_c[n(2k+q)+p(2k+h)]}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (28)$$



Single horizontal load at apex

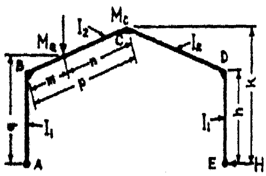
$$H=\frac{M_B\left[2h^2\frac{I_2}{I_1}+s(2h+k)\right]+M_c(s+p)(2k+h)}{4h^3\frac{I_2}{I_1}+2(s+p)(h^2+hk+k^2)} \quad (29)$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

SYMMETRICAL GABLE BENT

Two Moments of Inertia

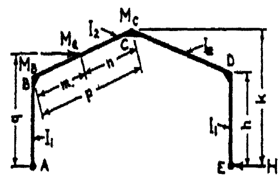


Single vertical load applied to slope.

$$H = \frac{M_a(2pq + mh + nk) + M_c[nq + ph + 2k(n+p)]}{4h^3\frac{I_2}{I_1} + 4p(h^2+hk+k^2)} \quad (30)$$

NOTE: For single vertical load applied at apex, the above value of H reduces to:

$$H = \frac{2M_c p(2k+h)}{4h^3\frac{I_2}{I_1} + 4p(h^2+hk+k^2)} \quad (31)$$

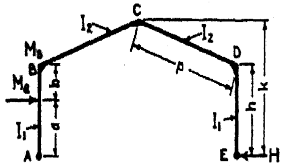


Single horizontal load applied to slope.

$$H = \frac{2M_B h^2\frac{I_2}{I_1} + M_B m(2h+q) + M_a(2pq + hm + nk) + M_C[nq + ph + 2k(n+p)]}{4h^3\frac{I_2}{I_1} + 4p(h^2+hk+k^2)} \quad (34)$$

NOTE: For single horizontal load P applied at apex:

$$H = \frac{P}{2} \quad (35)$$

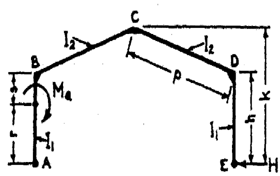


Single horizontal load applied to column.

$$H = \frac{M_a\left[(3h^2 - a^2)\frac{I_2}{I_1} + 3p(h+k)\right]}{4h^3\frac{I_2}{I_1} + 4p(h^2+hk+k^2)} \quad (32)$$

NOTE: For single horizontal load applied at top of column, the above value of H reduces to:

$$H = \frac{M_B\left[2h^2\frac{I_2}{I_1} + 3p(h+k)\right]}{4h^3\frac{I_2}{I_1} + 4p(h^2+hk+k^2)} \quad (33)$$



Crane moment applied to column.

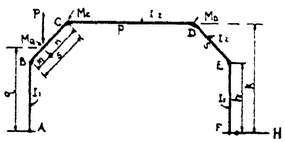
$$H = \frac{3M_a\left[s\frac{I_2}{I_1}(r+h) + p(h+k)\right]}{4h^3\frac{I_2}{I_1} + 4p(h^2+hk+k^2)} \quad (36)$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

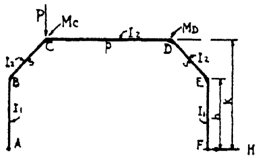
SYMMETRICAL HIP BENT

Two moments of inertia



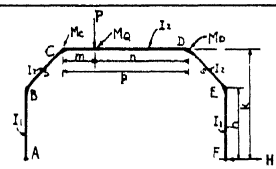
Single vertical load on slope

$$H=\frac{M_a[m(2q+h)+n(2q+k)]+M_C[n(2k+q)+3pk]+M_D[s(2k+h)+3pk]}{4h^3\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad - - (37)$$



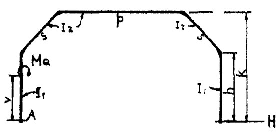
Single vertical load P at hip.

$$H=\frac{(M_C+M_D)[s(2k+h)+3pk]}{4h^3\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad - - - - - - - (38)$$



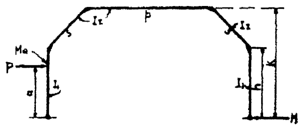
Single vertical load on cross beam.

$$H=\frac{M_C[s(2k+h)+3mk]+3pkM_a+M_D[s(2k+h)+3nk]}{4h^3\cdot\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad . . . (39)$$



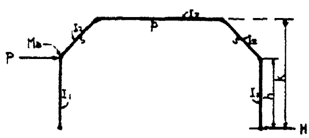
Crane moment applied to column

$$H=\frac{3M_a\left[s(h+k)+pk+(h^2-v^2)\frac{I_2}{I_1}\right]}{4h^3\cdot\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad - - - (40)$$



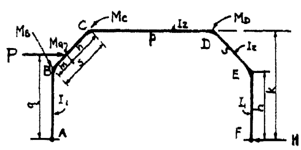
Single horizontal load applied to column

$$H=\frac{3M_a\left[s(h+k)+pk+(h^2-\frac{a^2}{3})\frac{I_2}{I_1}\right]}{4h^3\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad - - - (41)$$



Single horizontal load at top of column

$$H=\frac{3M_B\left[s(h+k)+pk+\frac{2h^2}{3}\cdot\frac{I_2}{I_1}\right]}{4h^3\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad . . . . . . (42)$$



Single horizontal load applied to slope.

$$H=\frac{M_B\left[2h^2\frac{I_2}{I_1}+m(2h+q)\right]+M_a[m(2q+h)+n(2q+k)]+M_C[n(2k+q)+3pk]+M_D[s(2k+h)+3pk]}{4h^3\frac{I_2}{I_1}+4s(h^2+hk+k^2)+6pk^2} \quad (43)$$

NOTE: For single horizontal force P applied to end of cross beam,

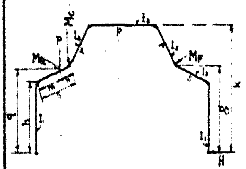
$$H=\frac{P}{2} \quad - - - - - - - - - (44)$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

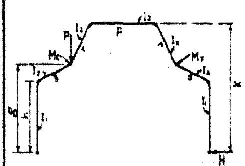
SYMMETRICAL MONITOR BENT

Two moments of inertia



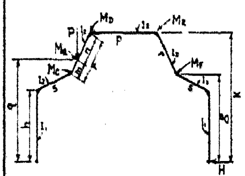
Single vertical load on lower slope.

$$H=\frac{M_Q(2qs+mh+ng)+M_C[n(2g+q)]+M_F[s(2g+h)]+3(M_C+M_F)[rg+k(p+r)]}{4h^3\frac{I_2}{I_1}+6pk^2+4s(g^2+gh+h^2)+4r(g^2+gk+k^2)} \qquad (45)$$



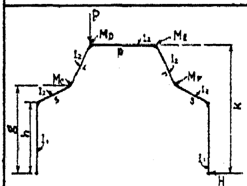
Single vertical load at top of lower slope.

$$H=\frac{3(M_C+M_F)\left[\frac{s}{3}(2g+h)+pk+r(g+k)\right]}{4h^3\frac{I_2}{I_1}+6pk^2+4s(g^2+gh+h^2)+4r(g^2+gk+k^2)} \qquad (46)$$



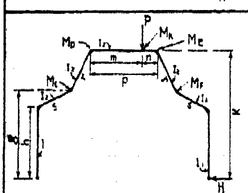
Single vertical load on upper slope.

$$H=\frac{M_C[s(2g+h)+m(2g+q)]+M_Q(2rq+mg+nk)+M_D[nq+k(2n+3p)]+M_E[rg+k(2r+3p)]+M_F[r(2g+k)+s(2g+h)]}{4h^3\frac{I_2}{I_1}+6pk^2+4s(g^2+gh+h^2)+4r(g^2+gk+k^2)} \qquad (47)$$



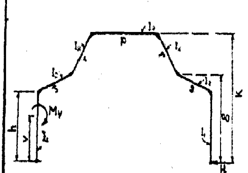
Single vertical load at hip

$$H=\frac{(M_C+M_F)[s(2g+h)+r(2g+k)]+(M_D+M_E)[r(2k+g)+3pk]}{4h^3\frac{I_2}{I_1}+6pk^2+4s(g^2+gh+h^2)+4r(g^2+gk+k^2)} \qquad (48)$$



Single vertical load on cross beam.

$$H=\frac{(M_C+M_F)[r(2g+k)+s(2g+h)]+M_D[r(2k+g)+3mk]+3pkM_K+M_E[r(2k+g)+3nk]}{4h^3\frac{I_2}{I_1}+6pk^2+4s(g^2+gh+h^2)+4r(g^2+gk+k^2)} \qquad (49)$$



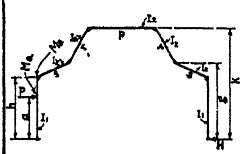
Crane moment applied to column

$$H=\frac{3M_V\left[(h^2-v^2)\frac{I_2}{I_1}+s(g+h)+r(g+k)+pk\right]}{4h^3\frac{I_2}{I_1}+6pk^2+4s(g^2+gh+h^2)+4r(g^2+gk+k^2)} \qquad (50)$$

VALUES OF H FOR HINGED FRAMES

Concentrated Loads

SYMMETRICAL MONITOR BENT – Two moments of inertia

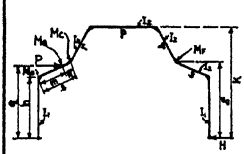


Single horizontal load applied to column.

$$H = \frac{3M_A\left[\left(h^2 - \frac{g^2}{3}\right)\frac{I_2}{I_1} + s(g+h) + r(g+k) + pk\right]}{4h^3\frac{I_2}{I_1} + 6pk^2 + 4s(g^2+gh+h^2) + 4r(g^2+gk+k^2)} \qquad (51)$$

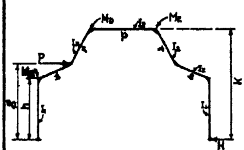
When load P is applied to top of column, formula (51) becomes:

$$H = \frac{3M_B\left[\frac{2}{3}h^2\frac{I_2}{I_1} + s(g+h) + r(g+k) + pk\right]}{4h^3\frac{I_2}{I_1} + 6pk^2 + 4s(g^2+gh+h^2) + 4r(g^2+gk+k^2)} \qquad (52)$$



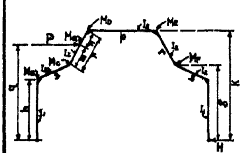
Single horizontal load applied to lower slope

$$H = \frac{M_B\left[2h^2\frac{I_2}{I_1} + m(2h+q)\right] + M_G(2rq+mh+ng) + M_C\left[n(2g+q)\right] + M_F\left[s(2g+h)\right] + 3(M_C+M_F)\left[rg+k(r+p)\right]}{4h^3\frac{I_2}{I_1} + 6pk^2 + 4s(g^2+gh+h^2) + 4r(g^2+gk+k^2)} \qquad (53)$$



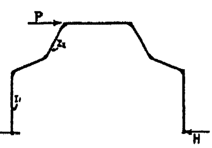
Single horizontal load applied at top of lower slope

$$H = \frac{M_B\left[2h^2\frac{I_2}{I_1} + s(2h+g)\right] + 3(M_D+M_E)\left[\frac{s}{3}(2g+h) + r(g+k) + pk\right]}{4h^3\frac{I_2}{I_1} + 6pk^2 + 4s(g^2+gh+h^2) + 4r(g^2+gk+k^2)} \qquad (54)$$



Single horizontal load on upper slope

$$H = \frac{M_B\left[2h^2\frac{I_2}{I_1} + s(2h+g)\right] + M_C\left[m(2g+q) + s(2g+h)\right] + M_G\left[m(2q+g) + n(2q+k)\right] + M_D\left[n(2k+q) + 3pk\right] + M_E\left[r(2k+g) + 3pk\right] + M_F\left[r(2g+k) + s(2g+h)\right]}{4h^3\frac{I_2}{I_1} + 6pk^2 + 4s(g^2+gh+h^2) + 4r(g^2+gK+K^2)} \qquad (55)$$



Single horizontal load P applied to end of cross beam.

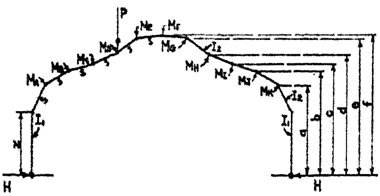
$$H = \frac{P}{2} \qquad (56)$$

Values of H for Hinged Frames

Concentrated Loads

SYMMETRICAL TWO HINGE ARCH BENT OF ANY SHAPE

Two moments of inertia



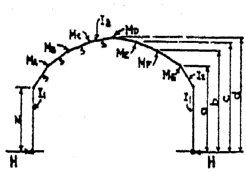
ARCH RING DIVIDED INTO TWELVE EQUAL STRAIGHT LINE SEGMENTS.

Single vertical load at any panel point i.e. junction of straight line segments

OR

Any number of equal or unequal vertical loads applied to some or to all panel points simultaneously.

$$H=\frac{(M_A+M_K)(z+4a+b)+(M_B+M_J)(a+4b+c)+(M_C+M_I)(b+4c+d)+(M_D+M_H)(c+4d+e)+(M_E+M_G)(d+4e+f)+2M_F(2f+e)}{\frac{4z^3}{3}\cdot\frac{I_2}{I_1}+4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+f^2)} \quad (57)$$

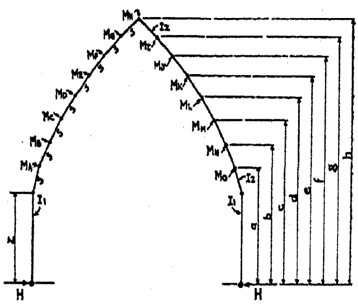


ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS LESS THAN TWELVE. (8 SHOWN)

Loading as above.

Formula (57) above can be used without recalculation by decreasing the number of terms. Thus, for an EIGHT equal straight segment arch bent, the value of H reads:

$$H=\frac{(M_A+M_G)(z+4a+b)+(M_B+M_F)(a+4b+c)+(M_C+M_E)(b+4c+d)+2M_D(2d+c)}{\frac{4z^3}{3}\cdot\frac{I_2}{I_1}+4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+d^2)} \quad (58)$$



ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS GREATER THAN TWELVE. 16 SHOWN

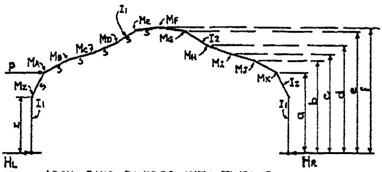
Loading as above.

Formula (57) above can be used without recalculation by increasing the number of terms. Thus, for a SIXTEEN equal straight segment arch bent, the value of H reads:

$$H=\frac{(M_A+M_O)(z+4a+b)+(M_B+M_N)(a+4b+c)+(M_C+M_M)(b+4c+d)+(M_D+M_L)(c+4d+e)+(M_E+M_K)(d+4e+f)+(M_F+M_J)(e+4f+g)+(M_G+M_I)(f+4g+h)+2M_H(2h+g)}{\frac{4z^3}{3}\cdot\frac{I_2}{I_1}+4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+2f^2+fg+2g^2+gh+h^2)} \quad (59)$$

Values of H for Hinged Frames

Concentrated Loads



ARCH RING DIVIDED INTO TWELVE EQUAL STRAIGHT LINE SEGMENTS.

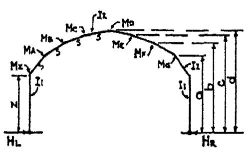
Single horizontal load applied to top of column or to any "panel point" i.e. junction of straight line segments

OR

Any number of equal or unequal horizontal loads applied to some or to all panel points and/or to column top simultaneously.

Note that for horizontal loads applied to the right half of the arch, the **H** given by the formula is **H_L**. See "Position and direction of H".

$$H_R=\frac{M_Z\left(\frac{2z^2}{5}\cdot\frac{I_2}{I_1}+2z+a\right)+(M_A+M_K)(z+4a+b)+(M_B+M_J)(a+4b+c)+(M_C+M_I)(b+4c+d)+(M_D+M_H)(c+4d+e)+(M_E+M_G)(d+4e+f)+2M_F(2f+e)}{\frac{4z^3}{5}\cdot\frac{I_2}{I_1}+4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+f^2)} \quad (60)$$

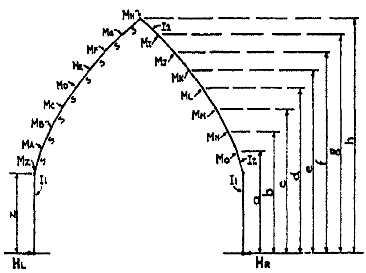


ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS LESS THAN TWELVE (8 SHOWN)

Loading as above

Formula (60) above can be used without recalculation by decreasing the number of terms. Thus, for an EIGHT equal straight segment arch bent, the value of **H_R** reads:

$$H=\frac{M_Z\left(\frac{2z^2}{5}\cdot\frac{I_2}{I_1}+2z+a\right)+(M_A+M_G)(z+4a+b)+(M_B+M_F)(a+4b+c)+(M_C+M_E)(b+4c+d)+2M_D(2d+c)}{\frac{4z^3}{5}\cdot\frac{I_2}{I_1}+4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+d^2)} \quad (61)$$



ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS GREATER THAN TWELVE. 16 SHOWN

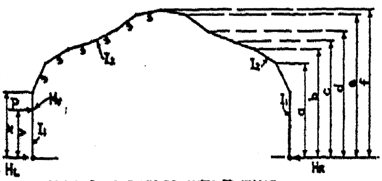
Loading as above

Formula (60) above can be used without recalculation by increasing the number of terms. Thus, for a SIXTEEN equal straight segment arch bent, the value of H reads:

$$H=\frac{M_Z\left(\frac{2z^2}{5}\cdot\frac{I_2}{I_1}+2z+a\right)+(M_A+M_O)(z+4a+b)+(M_B+M_N)(a+4b+c)+(M_C+M_M)(b+4c+d)+(M_D+M_L)(c+4d+e)+(M_E+M_K)(d+4e+f)+(M_F+M_J)(e+4f+g)+(M_G+M_I)(f+4g+h)+2M_H(2h+g)}{\frac{4z^3}{5}\cdot\frac{I_2}{I_1}+4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+2f^2+fg+2g^2+gh+h^2)} \quad (62)$$

VALUES OF H FOR HINGED FRAMES

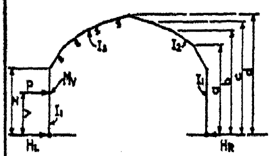
Concentrated Loads



ARCH RING DIVIDED INTO TWELVE EQUAL STRAIGHT LINE SEGMENTS

Single horizontal load applied to column

$$H_R = \frac{M_V\left[\left(\frac{3z^2-V^2}{s}\right)\frac{I_2}{I_1} + 6\left(\frac{z}{2}+a+b+c+d+e+\frac{f}{2}\right)\right]}{\frac{4z^3}{s}\cdot\frac{I_2}{I_1} + 4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+f^2)} \qquad (63)$$

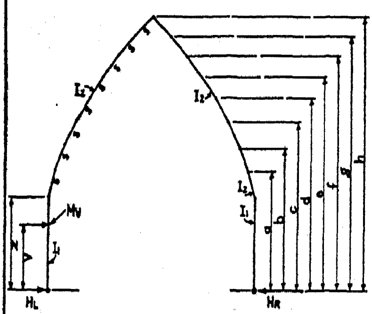


ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS LESS THAN TWELVE. (8 SHOWN)

Loading as above.

Formula (63) above can be used without recalculation by decreasing the number of terms. Thus, for an EIGHT equal straight segment arch bent, the value of H_R reads:

$$H_R = \frac{M_V\left[\left(\frac{3z^2-V^2}{s}\right)\frac{I_2}{I_1} + 6\left(\frac{z}{2}+a+b+c+\frac{d}{2}\right)\right]}{\frac{4z^3}{s}\cdot\frac{I_2}{I_1} + 4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+d^2)} \qquad (64)$$



ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS GREATER THAN TWELVE. (16 SHOWN)

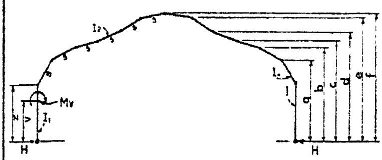
Loading as above.

Formula (63) above can be used without recalculation by increasing the number of terms. Thus, for a SIXTEEN equal straight segment arch bent, the value of H_R reads:

$$H_R = \frac{M_V\left[\left(\frac{3z^2-V^2}{s}\right)\frac{I_2}{I_1} + 6\left(\frac{z}{2}+a+b+c+d+e+f+g+\frac{h}{2}\right)\right]}{\frac{4z^3}{s}\cdot\frac{I_2}{I_1} + 4(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+2f^2+fg+2g^2+gh+h^2)} \qquad (65)$$

VALUES OF H FOR HINGED FRAMES

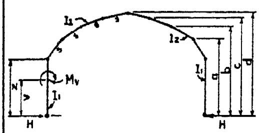
Concentrated Loads



ARCH RING DIVIDED INTO TWELVE EQUAL STRAIGHT LINE SEGMENTS

Moment applied to column

$$H = \frac{3M_v\left[\left(\frac{z^2-v^2}{5}\right)\frac{I_2}{I_1} + 2\left(\frac{z}{2}+a+b+c+d+e+\frac{f}{2}\right)\right]}{\frac{4z^3}{5}\,\frac{I_2}{I_1} + 4\left(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+f^2\right)} \quad (66)$$

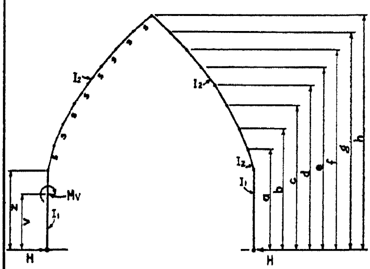


ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS LESS THAN TWELVE (8 SHOWN)

Loading as above

Formula (66) above can be used without recalculation by decreasing the number of terms. Thus, for an EIGHT equal straight segment arch bent, the value of H reads.

$$H = \frac{3M_v\left[\left(\frac{z^2-v^2}{5}\right)\frac{I_2}{I_1} + 2\left(\frac{z}{2}+a+b+c+\frac{d}{2}\right)\right]}{\frac{4z^3}{5}\,\frac{I_2}{I_1} + 4\left(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+d^2\right)} \quad (67)$$



ARCH RING DIVIDED INTO AN EVEN NUMBER OF EQUAL STRAIGHT LINE SEGMENTS GREATER THAN TWELVE. (16 SHOWN)

Loading as above.

Formula (66) above can be used without recalculation by increasing the number of terms. Thus, for a SIXTEEN equal straight segment arch bent, the value of H reads:

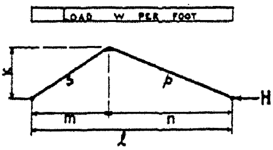
$$H = \frac{3M_v\left[\left(\frac{z^2-v^2}{5}\right)\frac{I_2}{I_1} + 2\left(\frac{z}{2}+a+b+c+d+e+f+g+\frac{h}{2}\right)\right]}{\frac{4z^3}{5}\,\frac{I_2}{I_1} + 4\left(z^2+za+2a^2+ab+2b^2+bc+2c^2+cd+2d^2+de+2e^2+ef+2f^2+fg+2g^2+gh+h^2\right)} \quad (68)$$

Values of H for Hinged Frames

Uniform Loads

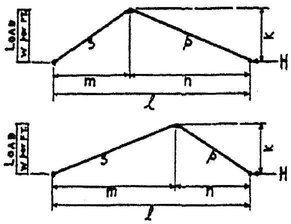
SAWTOOTH FRAME

CONSTANT MOMENT OF INERTIA



Uniform vertical load

$$H=\frac{w}{8}\cdot\frac{sm(4l-3m)+pn(4l-3n)}{k(s+p)}$$ (69)

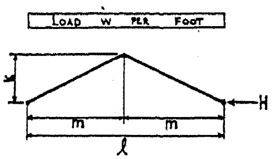


Uniform horizontal load

$$H=\frac{wk}{8l}\cdot\frac{5s+4(pn-sm)}{s+p}$$ (70)

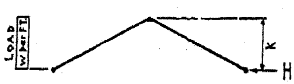
SYMMETRICAL GABLE FRAME

CONSTANT MT. OF INERTIA



Uniform vertical load

$$H=\frac{wm}{8k}(4l-3m)$$ (71)

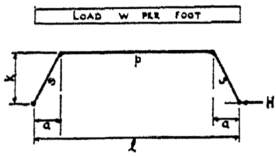


Uniform horizontal load

$$H=\frac{5wk}{16}$$ (72)

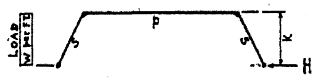
SYMMETRICAL HIP FRAME

CONSTANT MT. OF INERTIA



Uniform vertical load

$$H=\frac{w}{4}\cdot\frac{sa(4l-3a)+p[p^2+6a(l-a)]}{k(2s+3p)}$$ (73)

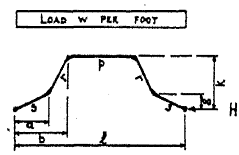


Uniform horizontal load

$$H=\frac{wk}{8}\cdot\frac{5s+6p}{2s+3p}$$ (74)

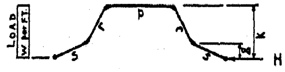
SYMMETRICAL MONITOR FRAME

CONSTANT MT. OF INERTIA



Uniform vertical load

$$H=\frac{w}{4}\cdot\frac{sga(4l-3a)+r[6a(l-a)(k+g)+2(b-a)(l-2a)(2k+g)-(5k+g)(b-a)^2]+pk[p^2+6b(l-b)]}{2sg^2+3pk^2+2r(g^2+gk+k^2)}$$ (75)

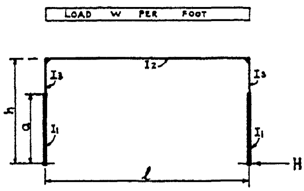


Uniform horizontal load

$$H=\frac{w}{8}\cdot\frac{sg^2(8k-3g)+5r(k^3+gk^2+g^2k-\frac{3}{5}g^3)+6pk^3}{2sg^2+3pk^2+2r(g^2+gk+k^2)}$$ (76)

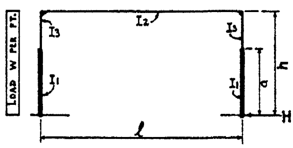
Values of H for Hinged Frames
Uniform Loads

RECTANGULAR BENT
Three Moments of inertia



Uniform vertical load

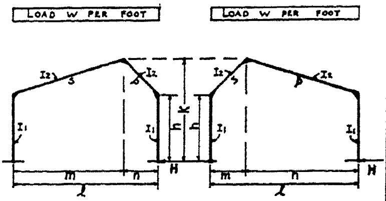
$$H=\frac{wh}{4}\cdot\frac{\ell^3}{2a^3\frac{I_2}{I_1}+3\ell h^2+(h^3-a^3)\frac{I_2}{I_3}} \qquad (77)$$



Uniform horizontal load

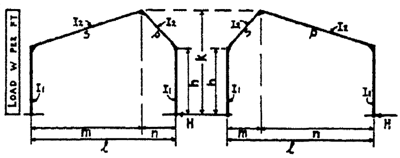
$$H=\frac{w}{8}\cdot\frac{a^3(8h-3a)\frac{I_3}{I_1}+6\ell h^3\frac{I_3}{I_2}+5(h-a)(h^3+ah^2+a^2h-\frac{3}{5}a^3)}{2a^3\frac{I_3}{I_1}+3\ell h^2\frac{I_3}{I_2}+(h^3-a^3)} \qquad (78)$$

SAWTOOTH BENT
Two Moments of inertia



Uniform vertical load

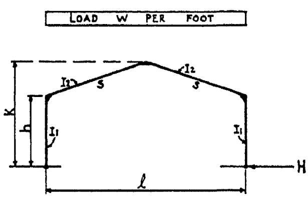
$$H=\frac{w\ell}{4}\cdot\frac{sm[(2k+h)-\frac{m}{2\ell}(3k+h)]+np[(2k+h)-\frac{n}{2\ell}(3k+h)]}{2h^3\frac{I_2}{I_1}+(s+p)(h^2+hk+k^2)} \qquad (81)$$



Uniform horizontal load

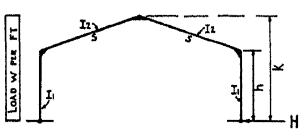
$$H=\frac{w}{8}\cdot\frac{h^3(8k-3h)\frac{I_2}{I_1}+5s(k^3+k^2h+kh^2-\frac{3}{5}h^3)+\frac{2k^2}{\ell}(2k+h)(np-sm)}{2h^3\frac{I_2}{I_1}+(s+p)(h^2+hk+k^2)} \qquad (82)$$

SYMMETRICAL GABLE BENT
Two Moments of inertia



Uniform vertical load

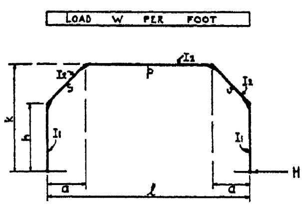
$$H=\frac{w\ell^2}{8}\cdot\frac{s[(2k+h)-\frac{1}{4}(3k+h)]}{h^3\frac{I_2}{I_1}+s(h^2+hk+k^2)} \qquad (79)$$



Uniform horizontal load

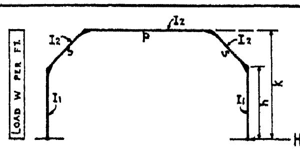
$$H=\frac{w}{16}\cdot\frac{h^3(8k-3h)\frac{I_2}{I_1}+5s(k^3+k^2h+kh^2-\frac{3}{5}h^3)}{h^3\frac{I_2}{I_1}+s(h^2+hk+k^2)} \qquad (80)$$

SYMMETRICAL HIP BENT
Two Moments of inertia



Uniform vertical load

$$H=\frac{w}{2}\cdot\frac{\ell sa[(2k+h)-\frac{a}{2\ell}(3k+h)]+2pk[\frac{p^2}{4}+\frac{3a}{2}(\ell-a)]}{2h^3\frac{I_2}{I_1}+3pk^2+2s(h^2+hk+k^2)} \qquad (83)$$



Uniform horizontal load

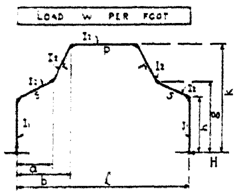
$$H=\frac{w}{8}\cdot\frac{h^3(8k-3h)\frac{I_2}{I_1}+5s(k^3+k^2h+kh^2-\frac{3}{5}h^3)+6pk^3}{2h^3\frac{I_2}{I_1}+3pk^2+2s(h^2+hk+k^2)} \qquad (84)$$

VALUES OF H FOR HINGED FRAMES

Uniform Loads

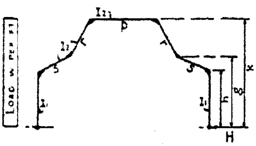
SYMMETRICAL MONITOR BENT

Two Moments of inertia



Uniform vertical load

$$H=\frac{w}{4}\cdot\frac{2sal\left[(2g+h)-\frac{a}{2l}(3g+h)\right]+r\left[6a(l-a)(k+g)+2(b-a)(l-2a)(2k+g)-(3k+g)(b-a)^2\right]+pk\left[p^2+6b(l-b)\right]}{2h^3\frac{I_2}{I_1}+3pk^2+2s(g^2+gh+h^2)+2r(g^2+gk+k^2)} \quad (85)$$



Uniform horizontal load

$$H=\frac{w}{8}\cdot\frac{h^3(8k-3h)\frac{I_2}{I_1}+s\left[6h(2k-h)(g+h)+4(g-h)(k-h)(2g+h)-(g-h)^2(3g+k)\right]+5r\left(k^3+k^2g+kg^2-\frac{3}{5}g^3\right)+6pk^3}{2h^3\frac{I_2}{I_1}+3pk^2+2s(g^2+gh+h^2)+2r(g^2+gk+k^2)} \quad (86)$$

A 40 foot arc-welded hinged gable bent with constant moment of inertia, loaded as indicated with nine vertical loads, three horizontal wind loads and a three ton crane is shown in Fig. 949. The craneway is supported by column brackets.

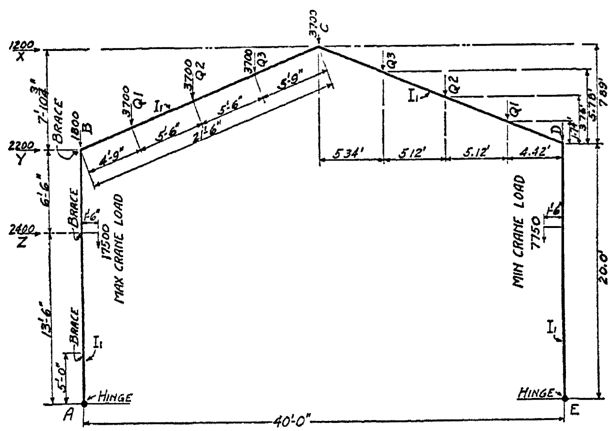
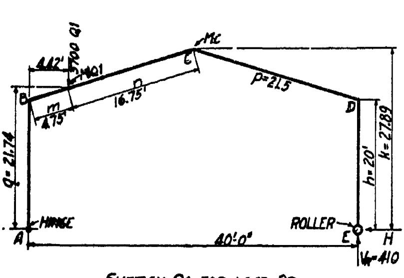


Fig. 949.

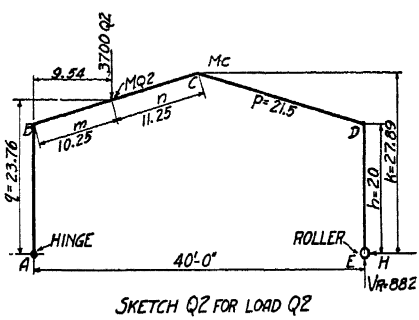
CALCULATIONS

1) Vertical Loads.

Loads B and D. Being applied directly on the columns, produce a direct column stress but have no other effect on the bent.

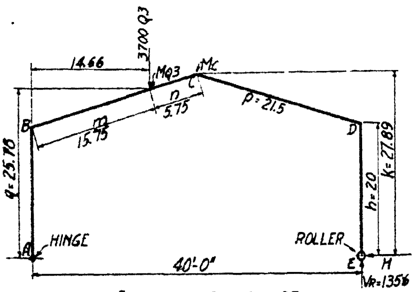


SKETCH Q1 FOR LOAD Q1.

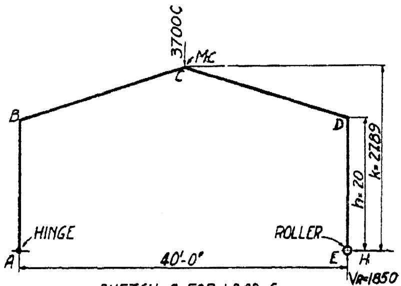


SKETCH Q2 FOR LOAD Q2

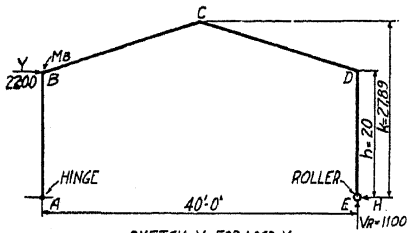
Loads Q_1. Remembering that, in the formulae given in these pages, the symbols M_B, M_Q, M_C, M_D etc. mean the moments at points B, Q, C, D etc. due to ONE given load on the structure when the structure has a ROLLER under one support, as indicated in Sketch Q_1, single load Q_1 gives the following V and M values:



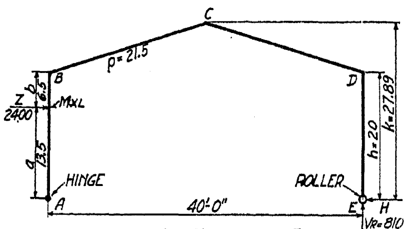
SKETCH Q3 FOR LOAD Q3



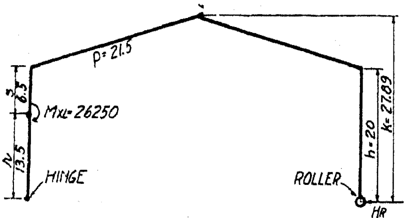
SKETCH C FOR LOAD C



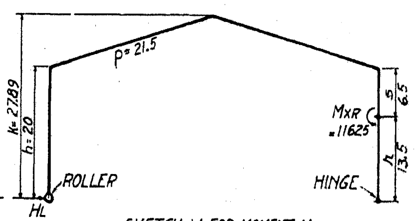
SKETCH Y FOR LOAD Y



SKETCH Z FOR LOAD Z



SKETCH W FOR MOMENT MXL
ON LEFT COLUMN



SKETCH V FOR MOMENT MXR
ON RIGHT COLUMN

$$V_R = \frac{3700 \times 4.42}{40} = 410; \quad M_{Q1} = 410\,(40 - 4.42) = 14540;$$

$$M_C = 410 \times 20 = 8200$$

From formula 30, we get the value of H by substituting the values indicated in Sketch Q_1 as follows:

$$H = \frac{14540\ (2 \times 21.5 \times 21.74 + 4.75 \times 20 + 16.75 \times 27.89) + 8200\ [16.75 \times 21.74 + 21.5 \times 20 + 2 \times 27.89\ (16.75 + 21.5)]}{4 \times 20^3 \times 1 + 4 \times 21.5\ (20^2 + 20 \times 27.89 + 27.89^2)}$$

$$H = \frac{14540 \times 1497 + 8200 \times 2928}{181265} = 253$$

Loads Q2. From sketch Q2,

$$V_R = \frac{3700 \times 9.54}{40} = 882;\ M_{Q2} = 882\ (40 - 9.54) = 26865;$$
$$M_C = 882 \times 20 = 17640$$

$$\text{From formula 30, } H = \frac{26865 \times 1540 + 17640 \times 2524}{181265} = 475$$

Loads Q3. From sketch Q3,

$$V_R = \frac{3700 \times 14.66}{40} = 1356;\ M_{Q3} = 1356\ (40 - 14.66) = 34360;$$
$$M_C = 1356 \times 20 = 27120$$

$$\text{From formula 30, } H = \frac{34360 \times 1584 + 27120 \times 2098}{181265} = 617$$

Load C. From sketch C,

$V_R = 1850; M_C = 1850 \times 20 = 37000.$

$$\text{From formula 31, } H = \frac{2 \times 37000 \times 21.5\ (2 \times 27.89 + 20)}{181265} = 665$$

Summing up the H values due to the individual vertical loads, and remembering that there are three loads Q1, Q2 and Q3, the total H for the vertical loads is:
$H_R = 2\ (253 + 475 + 617) + 665 = 3355$, acting from right to left; also $H_L = 3355$ at left support, acting from left to right, to balance H_R.

2) Horizontal loads.

$$\text{Load X. By formula 33, } H = \frac{1200}{2} = 600$$

$$\text{Also } V_R = \frac{1200 \times 27.89}{40} = 837 \text{ (Fig. 949)}$$

Load Y. From sketch Y,

$$V_R = \frac{2200 \times 20}{40} = 1100;\ M_B = 1100 \times 40 = 44000$$

From formula 11, $H = \dfrac{44000\,[2 \times 20^2 \times 1 + 3 \times 21.5\,(20 + 27.89)\,]}{181265}$

$= 945$

Load Z. From sketch Z,

$$V_R = \frac{2400 \times 13.5}{40} = 810 \quad M_{XL} = 810 \times 40 = 32400$$

From formula 32, H =

$$\frac{32400\,[3 \times 20^2 - 13.5^2 + 3 \times 21.5\,(20 + 27.89)]}{181265} = 735$$

Summing up the H (right support) reactions due to the individual horizontal wind loads, the total H for the horizontal loads is: $H_R = 600 + 945 + 735 = 2280$ acting against the wind, from right to left, and $H_L = 600 + (2200 - 945) + (2400 - 735) = 3520$ also acting against the wind from right to left.

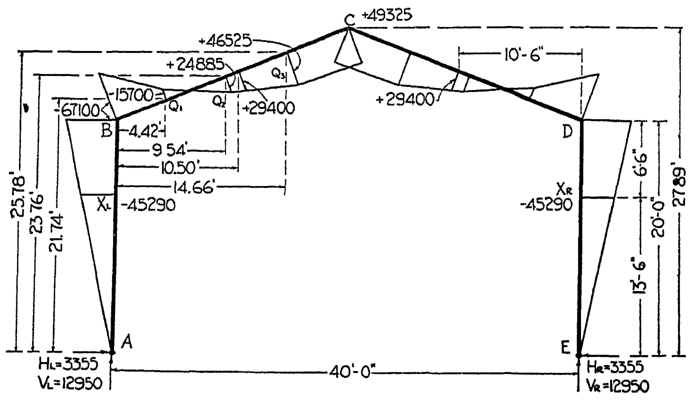
3) Three ton crane load.

The maximum vertical reaction that the crane can give is 17500 lbs. which is applied (Fig. 949) at the end of an arm $1\frac{1}{2}$ ft. long. The maximum crane moment is thus $17500 \times 1\frac{1}{2} = 26250$ ft. lbs. This is shown applied to the left column.
From sketch W and formula 36,

$$H_R = \frac{3 \times 26250\,[6.5 \times 1\,(13.5 + 20) + 21.5\,(20 + 27.89)]}{181265} = 542,$$

acting from right to left. At the left support, the balancing force $H_L = 542$, acting from left to right.

While the maximum crane moment is being exerted on the left column, the minimum crane moment is simultaneously acting on the right column. The minimum crane load (Fig. 949) is 7750 lb. acting



MOMENT DIAGRAM FOR VERTICAL LOADS

Fig. 950.

at the end of a $1\frac{1}{2}$ ft. arm. The moment is $7750 \times 1\frac{1}{2} = 11625$ ft. lbs. From sketch V and from sketch V and formula 36, $H_L = 240$ acting from left to right. This force is balanced at the right support by a force of 240 acting from right to left.

The value of H could also be obtained from sketch W by proportion of the moments on the left and right columns, thus:

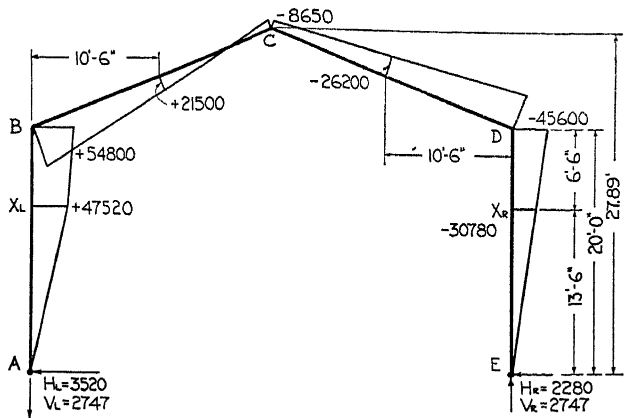
$$H_L = \frac{11625}{26250} \times 542 = 240$$

The value of H for all loadings having been established, the ACTUAL moment at all points of the bent can now be found.

The moments for vertical loading are shown in Fig. 950:
At X_L, the moment is $3355 \times 13\frac{1}{2} = -45290$, the sign minus being used when the moment's direction causes tension on the outside of the frame.

At point B, the moment is $3355 \times 20 = -67100$.

At point Q1, the moment is $12950 \times 4.42 - 3355 \times 21.74 = -15700$ Similarly, $M_{Q2} = 12950 \times 9.54 - 3355 \times 23.76 - 3700 \times 5.12 = 24885$ ft. lbs. $M_{Q3} = 12950 \times 14.66 - 3355 \times 25.78 - 3700(5.12 + 10.24) = 46525$ ft. lbs. $M_C = 12950 \times 20 - 3355 \times 27.89 - 3700\ (5.34 + 10.46 + 15.58)$ $= 49325$ ft lbs. The above values for vertical loads are indicated in Fig. 950 as the ordinates of the moment diagram.



MOMENT DIAGRAM FOR HORIZANTAL LOADS

Fig. 951.

Fig. 951 gives the moment diagram for the horizontal wind loads. At the left crane bracket, the moment due to wind is:

$M_{XL} = 3520 \times 13\frac{1}{2} = 47520$; Similarly, at points B, C, etc.,
$M_B = 3520 \times 20 - 2400 \times 6\frac{1}{2} = 54800$;
$M_C = 2747 \times 20 - 2280 \times 27.89 = -8650$;
$M_D = 2280 \times 20 = -45600$;
$M_{XR} = 2280 \times 13\frac{1}{2} = -30780$

Fig. 952 shows the moment diagram for maximum crane load applied to the left column. The crane moment from the bracket is 26250 ft. lbs.

Remembering that moment values causing tension on the outside of the frame are written with a negative sign,

M_{XL} below bracket $= 542 \times 13\frac{1}{2} = -7315$ ft. lbs.
M_{XL} above bracket $= 26250 - 7315 = 18935$
$M_B = 26250 - 542 \times 20 = 15400$
$M_C = 656 \times 20 - 542 \times 27.89 = -2000$
$M_D = 542 \times 20 = -10840$
$M_{XR} = 542 \times 13\frac{1}{2} = -7315$

Fig. 953 gives the moment diagram values which exist in the frame simultaneously with the values given in Fig. 952 due to the minimum crane moment on the right hand column. The applied moment on the right column is 11625 ft. lbs.

$M_{XL} = 240 \times 13\frac{1}{2} = -3240$
$M_B = 240 \times 20 = -4800$
$M_C = 291 \times 20 - 240 \times 27.89 = -875$
$M_D = 11625 - 240 \times 20 = 6825$
M_{XR} below bracket $= 240 \times 13\frac{1}{2} = -3240$
M_{XR} above bracket $= 11625 - 3240 = 8385$

Splices.—Welded frames are so designed that most of the welding is done in the shop.

The maximum shipping height of structural material is about 12 feet. From the above factors, a welded frame, such as the one under consideration, will be shipped in three sections, field-spliced somewhere between points B-C and C-D and up-ended into position. Proper splicing points need to be selected.

To minimize field-welding, splicing should be done at points that have as small a shear and a moment under all conditions of loading as possible.

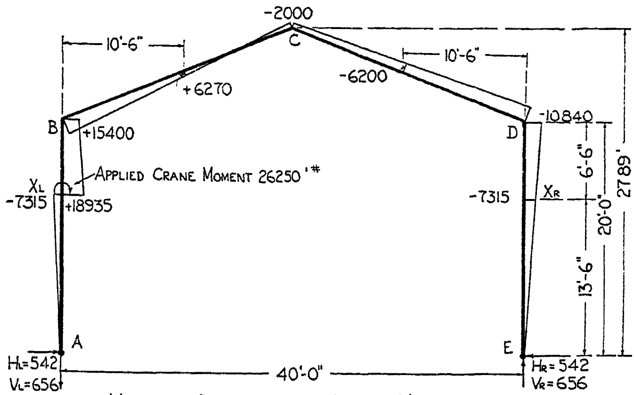
A glance at Figs. 950 to 953 inclusive, reveals that no loading causes any very large moment at the quarter point sections of the gable beam, i.e. at points about 10 feet from the columns.

Consider then a section 10′–6″ from the center line of columns, so as to clear the connections of the purlins coming in at points Q2, Fig. 949.

From Fig. 950, it will be noted that the vertical loads cause a positive moment of 29400 ft. lbs. at this point; from Fig. 951, the wind loads cause a positive moment of 21500 ft. lbs. at the same point; the maximum crane load adds a moment of 6270 ft. lbs., Fig. 952, while the minimum crane load, Fig. 953, causes a negative moment of –2740 ft. lbs. at this same point. We then have a total positive moment at the proposed splice point

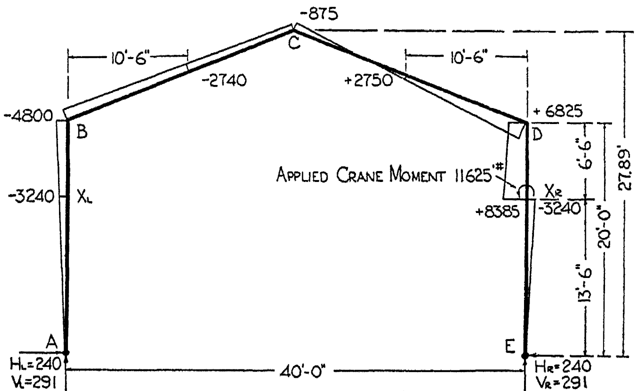
$M_S = 29400 + 21500 + 6270 - 2740 = 54430$ ft. lbs.

The maximum negative moment at the same point is due to wind and crane loading only. The wind produces, Fig. 951, –26200 ft. lbs.; the max. crane load, Fig. 952, adds –6200 ft. lbs. while the minimum crane load contributes a positive moment of 2750 ft. lbs. At the same time, even if there is no live load on the roof when these wind and crane loads are applied, there exists the DEAD LOAD of the roof. Assuming that this



MOMENT DIAGRAM FOR CRANE MOMENT
APPLIED TO LEFT COLUMN.

Fig. 952.



MOMENT DIAGRAM FOR CRANE MOMENT
APPLIED TO RIGHT COLUMN.

Fig. 953.

dead load amounts to 30% of the total vertical load, it contributes a positive moment equal to 30% x 29400 ft. lbs., Fig. 950, or 8820 ft. lbs. The max. negative moment at the proposed splice points is then
$M_S = -26200 - 6200 + 2750 + 8820 = -20830$ ft. lbs.

Design Moments.—From the moment diagrams, Figs. 950 to 953 incl., the design moments, i.e. the moments actually needed to make the design, are obtained.

Gable Beam.—The maximum positive moment occurs in the center of the beam with vertical loads only, no wind, no crane. From Fig. 950,

$M_C = \boxed{49325 \text{ ft. lbs.}}$

The max. negative moment occurs at point D and is due to a combination of vertical, wind and crane loads. From Figs. 950, 951, 952, 953, this maximum negative moment at point D is

$M_D = -67100 - 45600 - 10840 + 6825 = \boxed{-116715 \text{ ft. lbs.}}$

The maximum positive moment at the ends of the gable beam occurs with wind and crane loads only. From Fig. 951, at point B, the wind moment is 54800 ft. lbs.; the maximum crane load adds 15400 ft. lbs., Fig. 952, while the minimum crane load, Fig. 953, contributes simultaneously a negative moment of –4800 ft. lbs. Coincidently, just as was noted above for maximum negative moment at the splice points, the DEAD LOAD of the roof, taken at 30% of the total vertical load, contributes a negative moment of 30% of the vertical load moment at point B, Fig. 950, i.e. 30% x – 67100 = – 20100 ft. lbs. The maximum positive moment at B is therefore, $M_B = 54800 + 15400 - 4800 - 20100 = 45300$ ft. lbs. This is not a design moment since the negative moment at the gable beam ends figured just above for point D is much greater than this.

Columns.—The maximum column moments, at the top and at the bracket, are both negative moments. At the top, the moment, naturally, is the same as at the ends of the gable beam, i.e.

$\boxed{-116715 \text{ ft. lbs.}}$

At the bracket, the maximum moment is due to combined vertical, wind and crane loads. From Figs. 950, 951, 952, 953,

$M_{XR} = -45290 - 30780 - 7315 - 3240 = \boxed{-86625 \text{ ft. lbs.}}$

Splices.—The maximum moment for which the field splices are to be designed has been found above to be the positive moment due to vertical, wind and crane action, amounting to $\boxed{54430 \text{ ft. lbs.}}$

The moments noted above which are enclosed in a rectangular border are the DESIGN MOMENTS for this frame, i.e. the moments governing the design of material and welded joints. They are:

Gable beam 49325 ft. lbs. at center, from Fig. 950.
Gable beam – 116715 ft. lbs. at hips, from Figs. 950, 951, 952, 953.
Columns –86625 ft. lbs. at brackets, from Figs. 950, 951, 952, 953.
Field splices 54430 ft. lbs. $10\frac{1}{2}$ ft. from columns, Figs. 950, 951, 952, 953.

Proportions.—The moment at the junction of the gable beam to the columns is due to a combination of vertical, wind and crane loads. For such combined loads, stresses 33% greater than the usually allowed stresses are generally employed. Furthermore, the junction of beam and column is a point that must be effectively braced, laterally, especially opposite the compression (lower) flange of the beam. At this point, therefore, the maximum allowed stress will be 18000 x 133% = 24000 lbs. per sq. in. Assuming that both beam and column are made from a 16"-40 lb. I, Fig. 954, the maximum beam stress is

$$f = \frac{H \operatorname{Cos} a}{A} + \frac{My}{I}$$

where H is the total force found above, Figs. 950 to 953 inclusive, due to combined vertical, wind and crane loads, M is the design moment at the joint, in inch pounds, y is half the beam depth, A is the area of the beam and I its moment of inertia.

$$\text{Then } f = \frac{(3355 + 2280 + 542 + 240)\ 0.93}{11.77} + \frac{116715 \times 12 \times 8}{515.5}$$

= 22245 lbs. per sq. in.

The maximum column stress is

$f = \frac{V}{A} + \frac{My}{I}$ where V is the total vertical column load

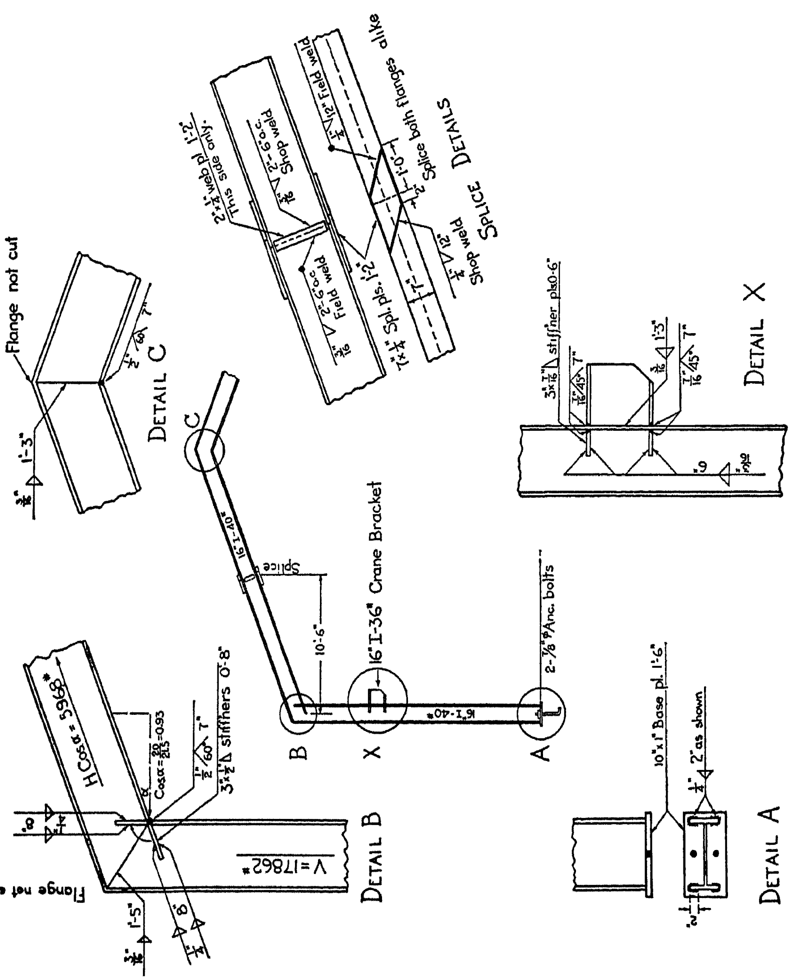


Fig. 954.

plus column reactions due to wind and crane loads, Figs. 950 and 953 inclusive.

$$\text{Then } f = \frac{12950 + 1800 + 2747 + 656 - 291}{11.77} + \frac{116715 \times 12 \times 8}{515.5}$$

$= 23250$ lbs. per sq. in.

Opposite the bottom of the crane bracket, the maximum column load is the same as at the column top plus 17500 lbs. from the crane. The design moment at this point is 86625 ft. lbs. Then

$$f = \frac{17862 + 17500}{11.77} + \frac{86625 \times 12 \times 8}{515.5} = 19130 \text{ lbs. per sq. in.}$$

This column is braced as shown in Fig. 949, so that its unsupported length is about $8\frac{1}{2}$ ft. Whence the stiffness ratio $l/r = \frac{8\frac{1}{2} \times 12}{1.5} = 68.$ The corresponding allowable column stress is $14321 \times 133\%$ for combined loads such as is the case here or 19100 lbs. per square inch.

On the strong axis, the column is unsupported from top to bottom. Whence $l/r = \frac{20 \times 12}{6.62} = 36$. The allowable stress is $15000 \times 133\%$ $= 20000$ lbs./sq. in.

The design moment at the points selected as field splices is 54430 ft. lbs. Referring to Pages 711 to 714, the shear at these points is 5550 lbs. from vertical loads, Fig. 950, 2747 lbs. from wind, Fig. 951, and 656 minus 291 lbs. from crane loads, Figs. 952 and 953 or a total of 8662 lbs.

The flanges need to be spliced for a stress of $\frac{54430 \times 12}{16 \times 133\%} = 30615$ lbs. while the web, due to the low shear across the section requires but light splicing.

The crane bracket will be made of a piece of 16″–36 lb. I, welded to the face of the column and backed up by stiffener plates connected to the column web as shown in Fig. 954. The bending moment is 26250 ft. lbs. whence the maximum flange stress is

$$f = \frac{My}{I} = \frac{26250 \times 12 \times 8}{446.3} = 5646 \text{ lbs. per sq. in.}$$

The flange of a 16″–36 lb. I is $7'' \times \frac{7}{16}''$. Assuming that the entire flange carries 5646 lbs. per sq. in., the outward pull on the column at the top of the bracket and the compression at the bottom would be $5646 \times 7 \times \frac{7}{16} = 17300$ lbs. or 2470 lbs. per inch of flange.

Welding, Cutting and Details.—Joint C, in the middle of the beam, is formed by V-cutting the beam as illustrated in Fig. 915, detail C, folding it and welding both web and flanges together. The design moment at this joint, 49325 ft. lbs. is only about half the capacity of the beam (97000 ft. lbs.); consequently no stiffener is used at this point. The flange stress is $\frac{49325 \times 12}{16 \times 7} = 5300$ lbs. per inch of flange. Fig. 954 calls for a full butt-weld $\frac{1}{2}''$ thick, or equal to the thickness of the flange of the beam. Its value @ 16000 lbs. per sq. in., the allowable unit stress for a shielded arc butt-weld in tension, is 8000 lbs. per lineal

inch. This welding is called for because this weld is located in an important position and is subject to considerable twisting when the frame is erected.

It might be noted here that that part of the frame comprised between the splices could be a 16″–36 lb. instead of 40 lb. I. The reason this is not done in this design is that the 36 lb. beam is $\frac{1}{8}''$ shallower than the 40 lb. beam which makes it hard to line up the sections in the shop. A saving of 75 lbs. weight is soon lost when the shop has to stop to make fine adjustments.

No important shears occur at point C so that the only web welding needed is enough to join the cut sections together. The web being $\frac{5}{16}''$ thick, Fig. 954 calls for a $\frac{3}{16}''$ weld on each side.

Joints B and D, at the junction of beam and column, are built along the lines indicated on Page 663, a very effective joint. The compression of the inner flange has to be delivered into the beam web while the compression in the bottom flange of the beam goes into the column web. Under heading "Proportions" above, it was shown that the maximum stress in those flanges is about 23000 lbs. per sq. in. so that the total force to be transmitted into the webs is approximately 23000 multiplied by the flange area, or $23000 \times 7 \times \frac{1}{2} = 80000$ lbs.

The triangular stiffener bars shown in Fig. 954, are $\frac{1}{2}''$ thick, the same thickness as the beam and column flanges, and are welded to the webs by 32″ of $\frac{1}{4}''$ fillets having a shielded arc value of 2500 lbs. per lineal inch, a total of 80000 lbs.

The butt-weld at the junction of the beam and column flanges is also proportioned for 80000 lbs. Its value per linear inch for shielded arc is $\frac{1}{2} \times 18750$ giving a total value of

$$18750 \times \tfrac{1}{2} \times 7 \times 133\% = 87000 \text{ lbs.}$$

Crane brackets. The 16″–36 lb. beam section used as crane brackets and the connections of the triangular gussets to the inside of the column flanges have a stress of 2470 lbs. per inch to handle, as noted under heading "Proportions". This stress could be handled by a $\frac{1}{4}''$ fillet. The design, however, calls for a full $\frac{7}{16}''$ butt-weld, Fig. 954, equal to the bracket beam's flange.

The web of the bracket has 17500 lbs. shear to handle including a 25% impact allowance. The welding of bracket web to column called for in Fig. 954 exceeds the requirements: the two $\frac{3}{16}''$ fillet welds called for have a capacity of about 60000 lbs. The pairs of triangular gussets are each intended to transmit 17300 lbs. into the column web: the $\frac{3}{16}''$ fillets connecting these gussets to the column web can handle more than twice that amount.

Where static stresses are involved, welding should be proportioned to the stresses. But where impact stresses are concerned, it is wise to recognize that they proceed from mere estimates and to provide reserve strength. Crane operation is not one of the gentler arts: many situations arise which cause unexpected demands on equipment and supports.

Column bases. Little welding is needed between the bottom of the columns and the base plates since these have been designed as hinged.

The anchor bolts are set so as to hold the frames in place after they have been upended into position, before any purlins have been

placed. Evidently, until then, the frames have a tendency to fall sideways. For this purpose, the welding is disposed around the ends of the column flanges so as to bring any tendency towards leaning over sideways to the anchor bolts.

Splices. At the splice sections, the flanges, as noted under heading "Proportions", are to be connected for 30615 lbs. Using a 7 x 1/4" splice plate, cut to the shape of a parallelogram, and 1/4" fillets, shielded arc value 2500 lbs. per linear inch, the length of welding required is $\frac{30615}{2500} = 12''$. One end of the splice plates is shop-welded, Fig. 954, the other, field-welded. The shape of the splice plates, in addition to providing the length of weld required, permits the field-welder to complete the flange welding without having to turn the assembled frame over.

The web is shown provided with a 2" x 1/4" splice bar, used largely to cover up the gap between the web ends, and secured by 2 x 3/16" tacks. This plate is placed on only one side of the web. This together with the design of the flange splice plates mentioned above, makes it quite unnecessary to turn the frame over in the field to complete the welding of the splices. The splicing is all done from a single set-up and the frame is then hoisted into place.

In connection with rigid frame splicing and assemblies in the field, it should be borne in mind that the overall width or span of such frames in the finished structure must be precisely the same as that of all the other adjacent identical frames. Therefore, a field templet should be provided, corresponding to the shop jigs, to permit setting up the component parts of each frame rapidly and accurately before proceeding with welding the field splices. Such a field templet is readily set up on the field assembly skids.

It is also a good idea to provide amid the skids a pit in the ground right under the frame splice points wherein the welder may stand in a comfortable position while welding up the field splices.

Bar Joists. — There are several types of bar joists of patented designs on the market which are built by welding. It is usually more economical to use these standard types of joists where design permits than to fabricate special bar joists. However, to meet special design requirements bar joists can be quickly and easily fabricated. In some cases this has been done on the construction site.

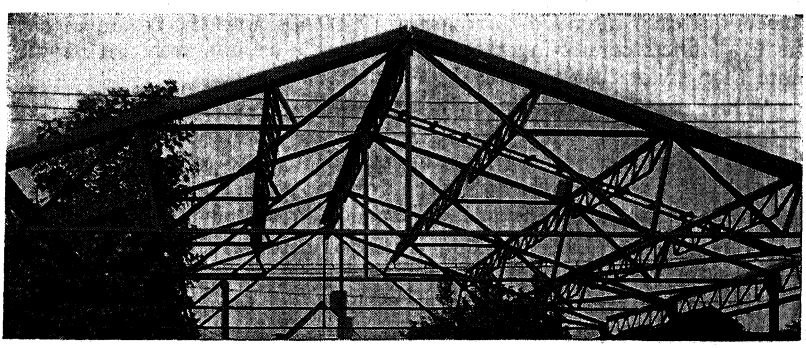


Fig. 955.

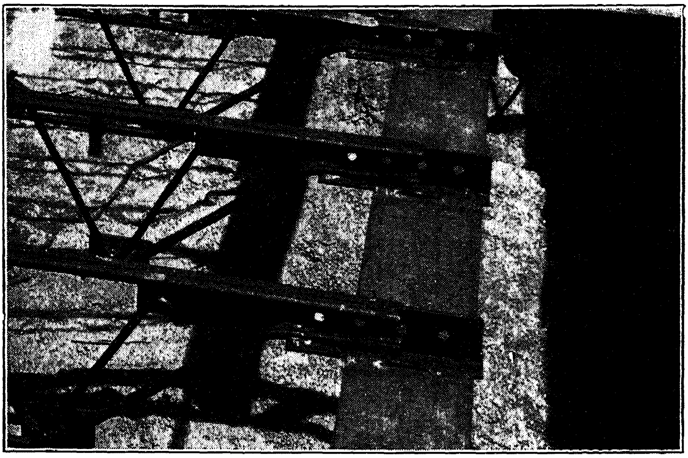


Fig. 956.

Fig. 955 shows the frame work of a job welding shop. The light roof trusses carry and are braced by bar-joist purlins which, in turn, support a metal deck roof. All connections are field-welded.

Arc welding also provides an efficient means for securing bar joists to their supporting members. A short tack weld on each side of the bearing plate at the ends of the bar joist permanently joins the joist to the framework. The Fig. 956 shows bar joint arc welded in place. This use of arc welding stiffens the entire structure because it actually ties in the framework, increasing its rigidity.

BAR FRAMES WITH DOUBLE WEBS OF ½″ RODS

	15″ Frame With 3″ Ch. Chords	12″ Frame With 3″ Ch. Chords	15″ Frame With 4″ Ch. Chords	12″ Frame With 4″ Ch. Chords
Resisting Moment	21000 ft. lbs.	16550 ft. lbs.	27500 ft. lbs.	21700 ft. lbs.
Shear Value	3400 lbs.	4150 lbs.	3400 lbs.	4150 lbs.
Max. load	6800 lbs.	8300 lbs.	6800 lbs.	8300 lbs.
Max. span with max. load uniformly distributed	24′–9″	16′–0″	30′–0″	21′–0″
Corresponding approx. deflection	1 1/16″	3/8″	1″	5/8″
Spacing for 40 lb. load with max. load on max. span.	6′–10″	13′–0″	5′–8″	9′–10″
Spacing for 140 lb. load with max. load on max. span	2′–0″	3′–9″	1′–7″	2′–10″
Weight	11.0 lbs./ft.	11.0 lbs./ft.	13.6 lbs./ft.	13.6 lbs./ft.

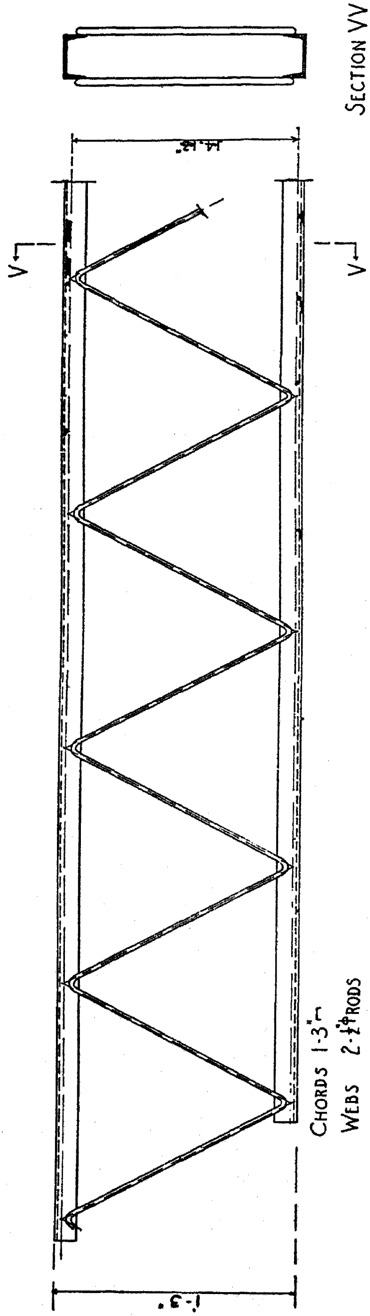


Fig. 957.

Bar Frames. — Arc welding permits economical design of bar frames. These frames are generally designed for channel chords with angles or round or flat bar forming the web. The arc welded design of bar frame, Fig. 957, illustrates a double web type. Data on this type is contained in the table on Page 719.

It will be observed that the single design shown in Fig. 957 and expanded to four sizes of frames in the table above covers spans ranging from 16 ft. to 30 ft., spacings from 1'-7" to 13 ft. and loads up to 140 lbs. per sq. ft.

Purlin Connections. — Purlins constitute the largest number of main pieces required in the frame of a mill building. They are commonly designed as rolled beams or channels. The fabrication of a purlin usually consists of two or three holes at each end for connection to the trusses and two or four holes in the web for the sag rods. This entails considerable handling which in turn increases costs.

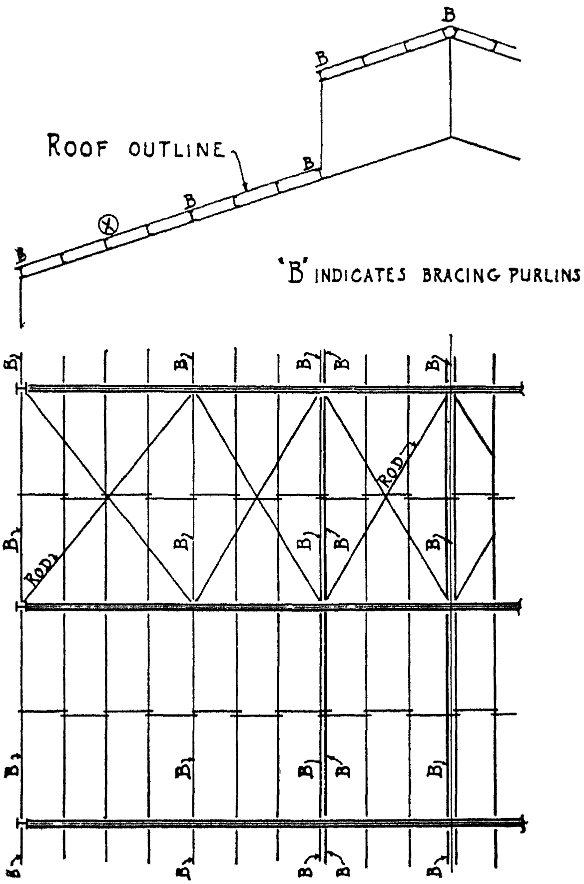


Fig. 958.

Transportation and handling costs may be reduced by shipping the largest possible number of purlins directly from the mill to the job.

Purlins which do not act as braces for the roof trusses need no holes, or at most, only holes for the sag rods. The ends are arc welded to the roof trusses; the sag rod holes may be quickly located and burned through at the job before erection, with ample accuracy for their purpose. It is essential that some simple means of locating the non-bracing purlins on the trusses be provided. Fig. 958 shows part of the roof frame of a mill building.

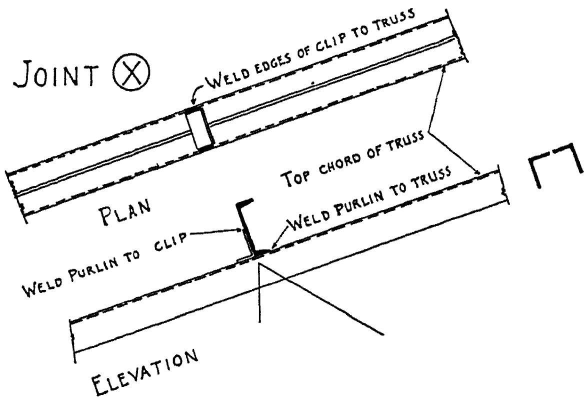


Fig. 959.

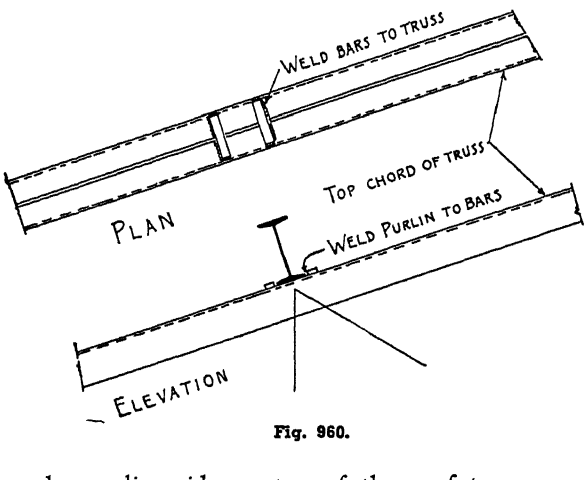


Fig. 960.

When the purlins ride on top of the roof trusses, as they most usually do, the simplest marker is the customary clip angle, Fig. 959, welded to the top chord of the truss. The purlin is laid up against

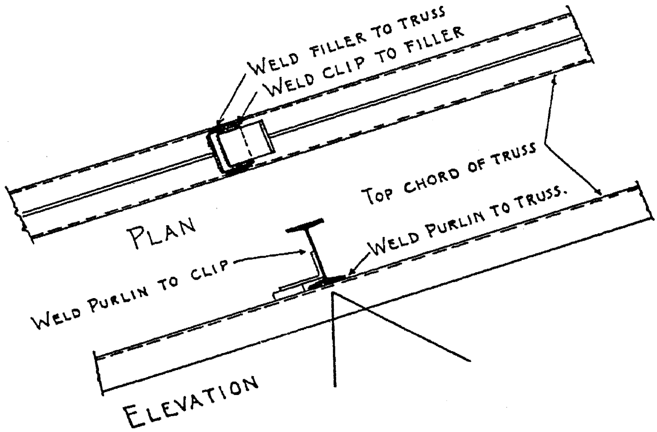


Fig. 961.

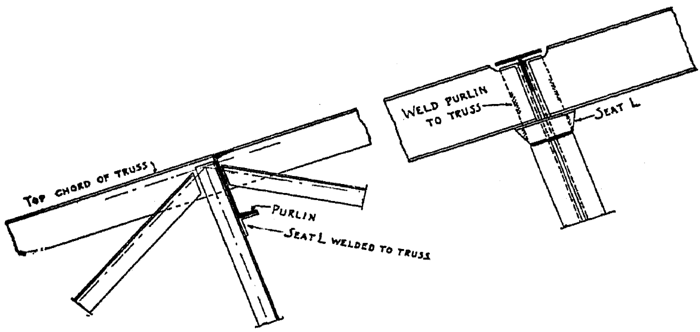


Fig. 962.

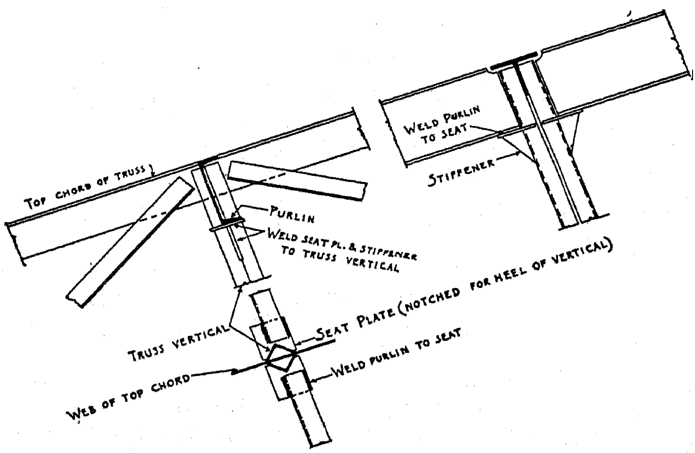


Fig. 963.

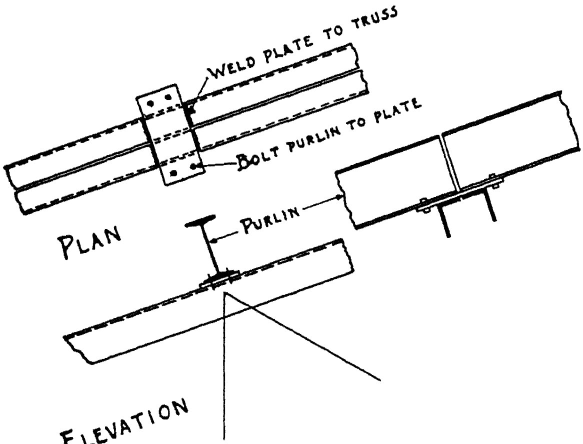


Fig. 964.

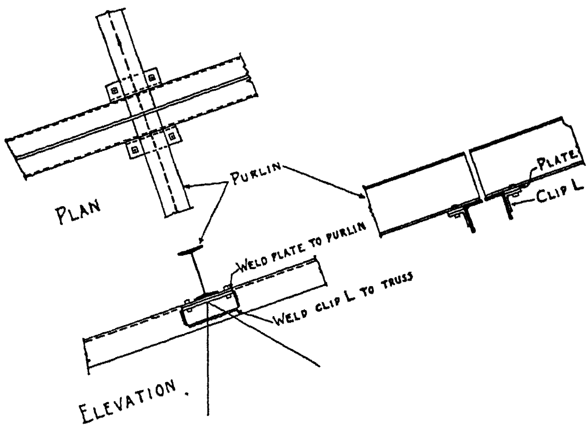


Fig. 965.

the clip and clamped to it or to the truss until welded. If the purlins are I-beams, a raised clip, Fig. 960, may be used, or the purlin, Fig. 961, may be set between a pair of bar markers.

If the purlins must frame flush with the supporting trusses, a suitable seat, Figs. 962 and 963, is provided on a truss web member, on which the purlins are landed.

Purlins which act as braces for the trusses require connection holes to permit lining up the trusses before the other purlins filling in between the braces, are set and welded. If the bracing purlins themselves are punched, they are bolted to seat plates welded to the truss chord, Fig. 964, or, if the framing is flush, seats are provided as in Figs. 962 and 963 and the purlins are bolted to the seat. After the trusses are lined up and the diagonal tie rods tightened, the bracing purlins are welded to the trusses.

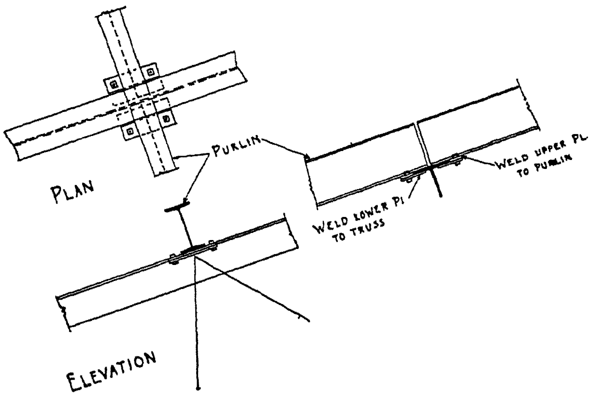


Fig. 966.

It is not, however, necessary to punch the bracing purlins: they may be bolted to the trusses by means of plates shop or field-welded to the bottom flange, as shown in Figs. 965 and 966. In this manner, even the bracing purlins may be shipped from the mill directly to the job.

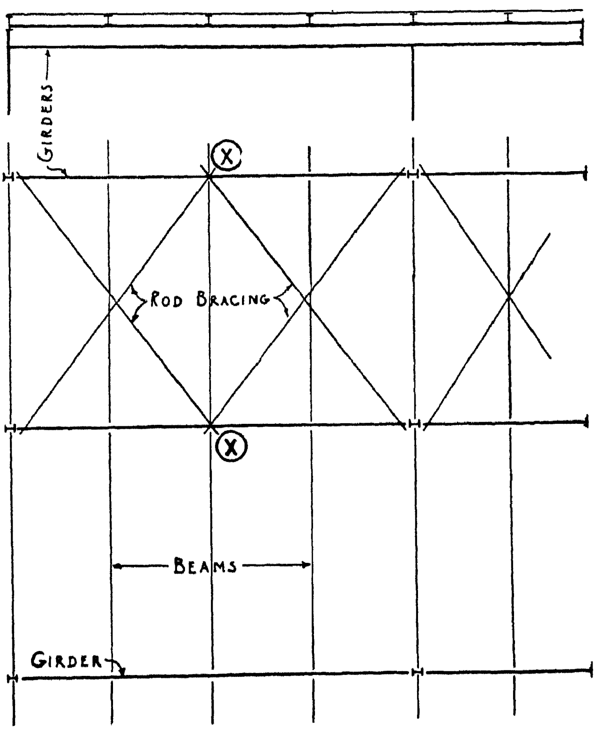


Fig. 967.

Rod Bracing.—Rods are particularly desirable for bracing purposes because they are adjustable. A number of simple welded connections for rod bracing are shown here.

Fig. 967 shows a frame in which the girder beams are rod-braced at intervals. The rods are placed diagonally, under the beams. A square shoulder against which to turn up the nuts may be provided by welding a clip angle on the web of the girder beam and providing a short slotted hole in the girder's web.

The arrangement shown in Fig. 968 can accommodate rods on a 30-degree angle, while, by turning the clip around, Fig. 969, a rod at 60 degrees may be provided for. By cutting one leg of a 6″x6″ clip angle, all intermediate angles can be suited.

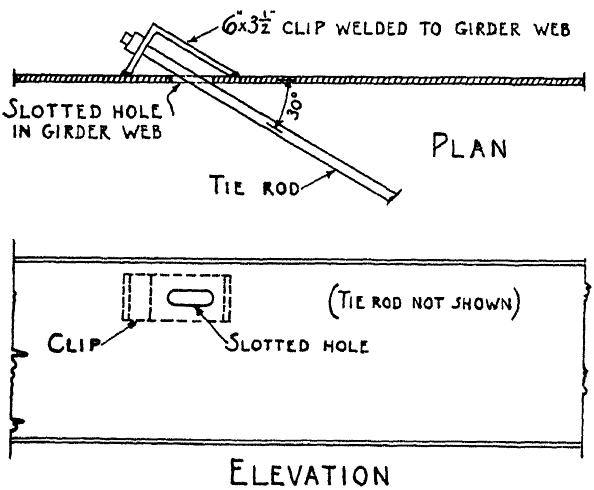


Fig. 968.

At points where two rods must be handled, such as at points X, Fig. 967, they may be placed one above the other and the nuts turned up on the opposite faces of a clip angle, Fig. 970, or of a bent plate, Fig. 971.

Rod bracing in mill buildings is not subjected to very great strains; nevertheless, the thickness of such clips or bent plates should be sufficient to prevent undue distortion which makes it harder to turn up the nuts. Where two rods come in together, it must be remembered that only one of the two is in action at any one time and the clip or plate should be proportioned accordingly.

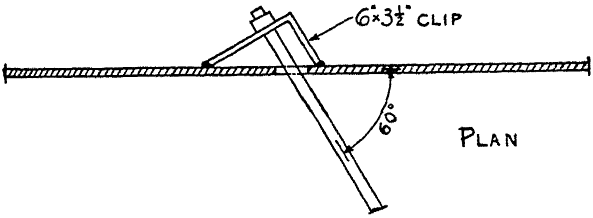


Fig. 969.

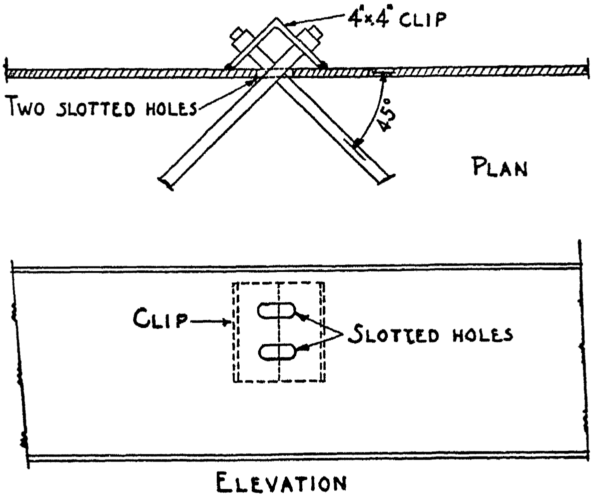


Fig. 970.

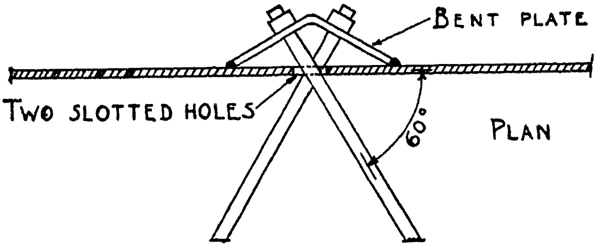


Fig. 971.

If the rod adjustment is to be made by turnbuckles or by sleeve-nuts instead of by the end nuts, skew washers for the ends of the rods may readily be provided by means of an angle clip with the

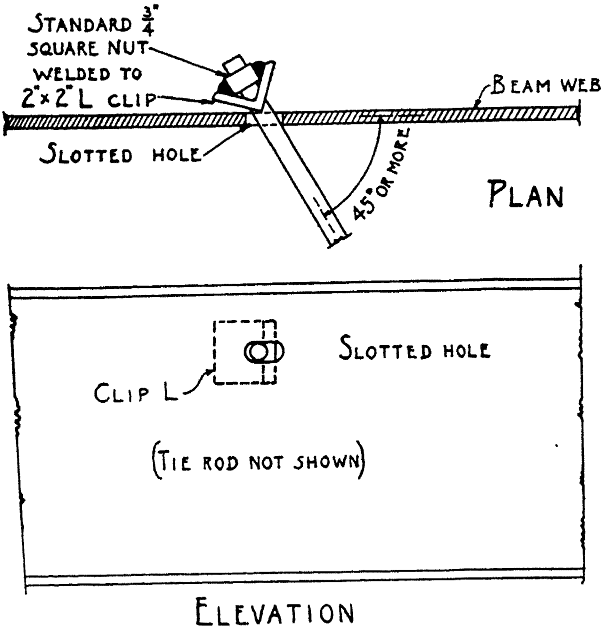


Fig. 972.

end nut welded thereto as shown in Fig. 972. The fillet not only secures the nut to the clip but prevents the legs of the angles from spreading.

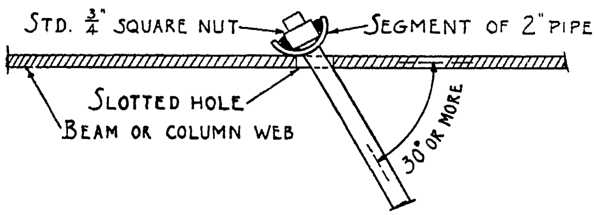


Fig. 973.

Instead of a clip angle, a short segment of pipe may be used as a washer, Fig. 973. Such skew washers may be used for a wide range of angles, care being taken to make the slotted hole of ample length in the braced member.

In Fig. 974, rods are employed for lining up the purlins and for bracing the supporting trusses. The clips may be attached either to the bottom of the purlins, as in Fig. 975, which is a detail of joint Y, or they may be attached directly to the underside of the top chord, as in Fig. 976, which is a detail of joint Z. The clips may, of course,

be welded to the purlins or to the chords by two fillets, one along each edge of the clip. However, the leg of the clip placed parallel to the rod brace is very effective in bringing the pull of the rod to the purlin or truss.

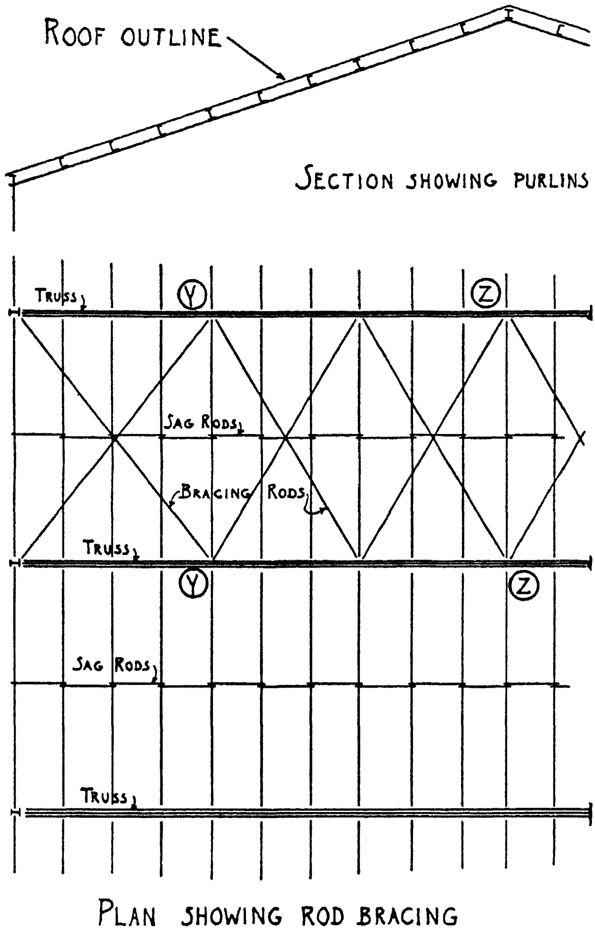


Fig. 974.

Fig. 977 is a part elevation of a mill building showing the eaves strut, the columns and one of the braced bays; the sash girts, carried by the outside flange of the columns, are not shown. The rod braces are attached to the columns by clips of the type shown in Fig. 968, Page 726. If desired, the clips may be carried across the column web, as in Fig. 978, so as to bring the pull of the rods to the column flanges.

It may be pointed out that, since the strains in rod bracing are not high, satisfactory turnbuckles for such rods may be made by welding two nuts to a pair of small tees as illustrated in Fig. 979. The

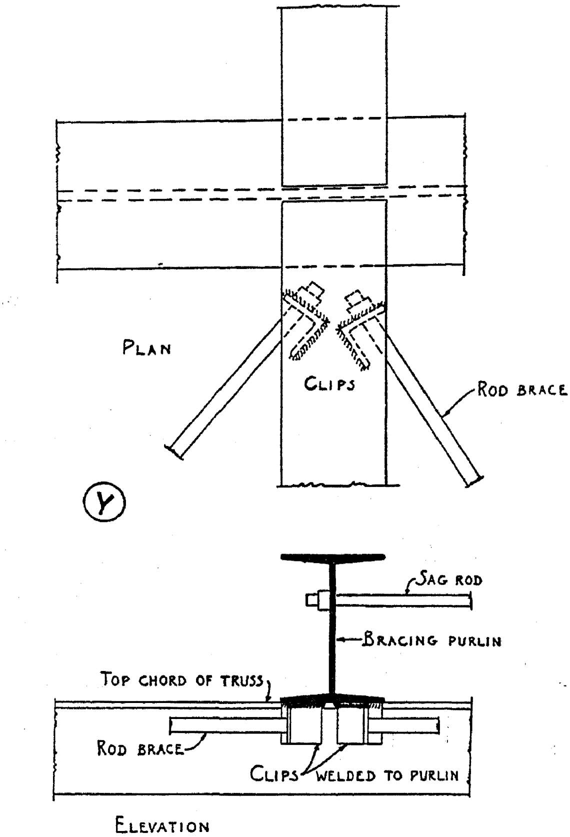


Fig. 975.

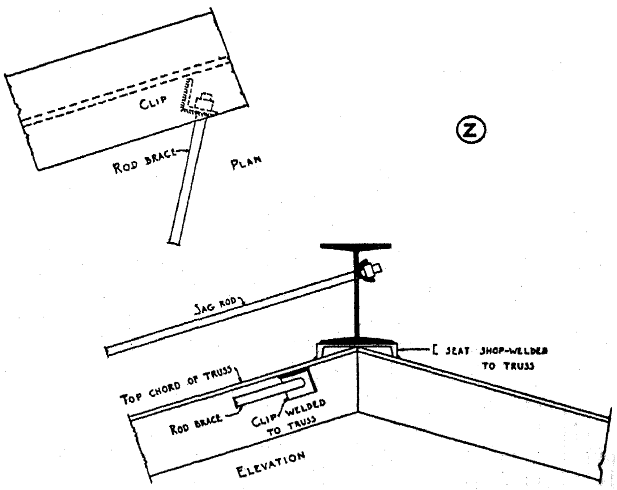


Fig. 976.

outstanding leg of the tees takes the bending when the turnbuckle is tightened. If flats are used instead of tees, they will bend when the turnbuckles are tightened up.

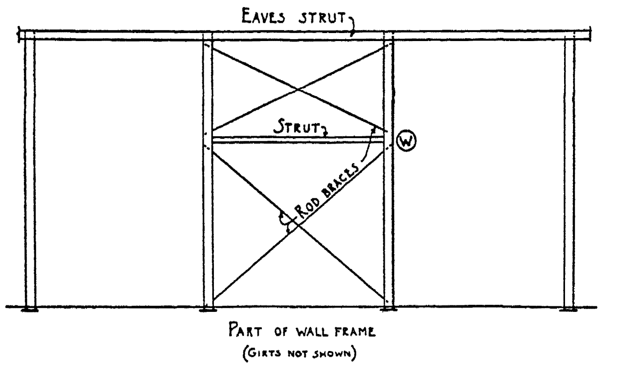


Fig. 977.

Sleeve-nuts also may be made, by welding two nuts to some small angles, as shown in Fig. 980. For such purposes, all nuts must be placed square to the axis of the rods and held that way during the welding. After that, the threads of the nuts should be trued up as they may be slightly out of line after welding.

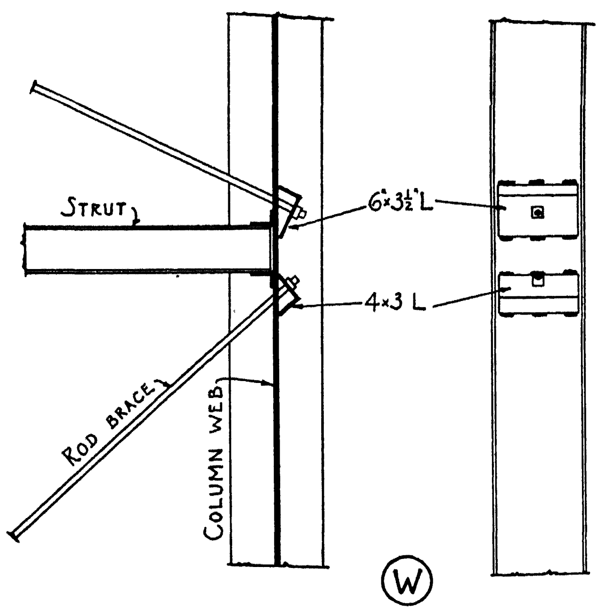


Fig. 978.

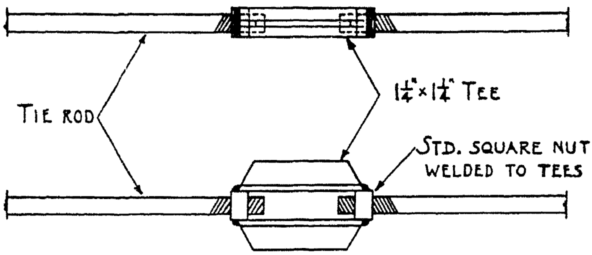


Fig. 979.

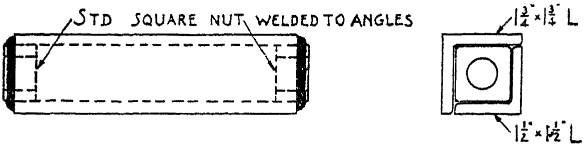


Fig. 980.

Angle Bracing. — Angle braces are often preferred to rods, particularly for wall bracing and as sway laterals over craneways. Fig. 981 shows a common angle wall-brace made of two diagonal angles turned back to back. If these angles are just bolted or welded to the columns, one of the two angles will often be found bowed out of line when the building is finished. To avoid this, the bolt holes are sometimes slotted at the lower end of each angle, the bolts in the slotted holes being eventually welded to the angles. This method has the merit of producing angle braces which are straight when the building is finished, but the braces are not practical for plumbing the building during erection.

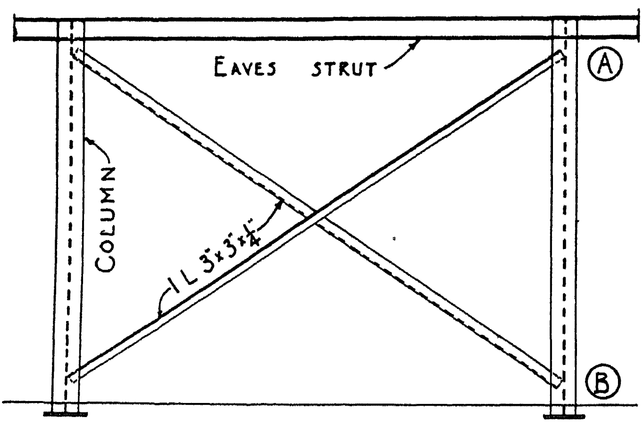


Fig. 981.

Fig. 982 shows an angle brace attached in adjustable fashion to the top of the column by means of a bolt engaging a square nut welded to the angle. The bolt passes through a slotted hole in the column

web and is turned up on a shoulder clip welded to the column. The axis of the bolt is very nearly in line with the center of gravity of the angle section and, as the nut is welded to both legs of the angle, the pull of the bolt is practically in line with the gravity axis of the angle.

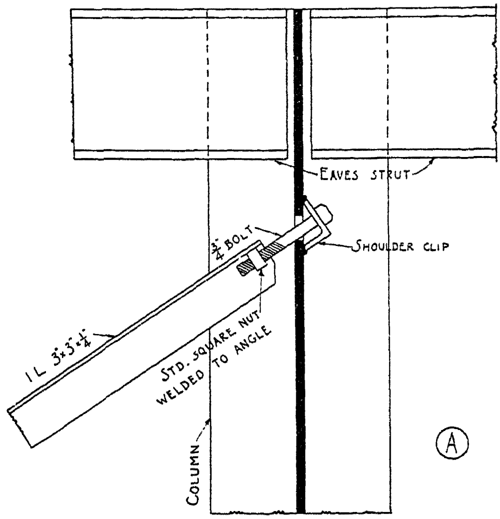


Fig. 982.

When the two sides of the column web are not accessible, as at corner columns, etc., the adjustment for the angle may be provided, as shown in Fig. 983, by replacing a short section of the angle with a right and left threaded bolt engaging square nuts welded to the angle at either end of the bolt. Another nut welded to the middle of the bolt forms a shoulder for turning up the bolt.

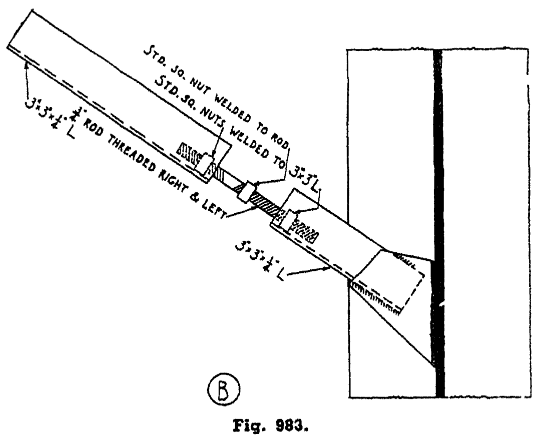
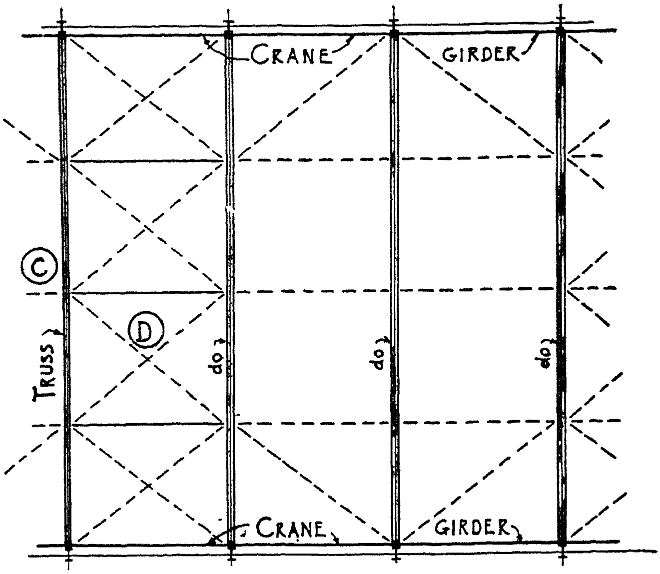


Fig. 983.



PART PLAN SHOWING BRACING OF BOTTOM CHORDS.

8"×6" H-STRUTS SHOWN THUS ————

3"×3"×¼" L TIES SHOWN THUS - - - - - -

Fig. 984.

Fig. 984 shows the bracing of a crane aisle, consisting of H-struts and angle ties placed in the plane of the bottom chord of the trusses and above the crane clearance. After the trusses and purlins are erected, the trusses are lined up and the bracing welded in position.

To assist in lining up the trusses, one end of the struts may be provided with a nut welded to the web and top flange, Fig. 985, by means of which the truss to which the strut is thus attached may be moved in or out. The diagonals are placed with the heel of the angle uppermost, one leg being welded to the strut and the other to the truss, forming a very compact connection.

Where the diagonals intersect, the upper diagonal *a* is cut into the lower one *b*, Fig. 986, and the two angles are welded to each other. If desired, a gusset may be welded across the lower angle *b* parallel to the direction of the upper angle *a* and directly below it to prevent any possible spreading of the legs of the lower angle due to the pull of the upper one.

Another way of attaching angles in adjustable fashion is shown in Fig. 987. A bent bolt is placed through a hole in the web of the strut; the end of the diagonal tie angle is provided with a ½″ shoulder

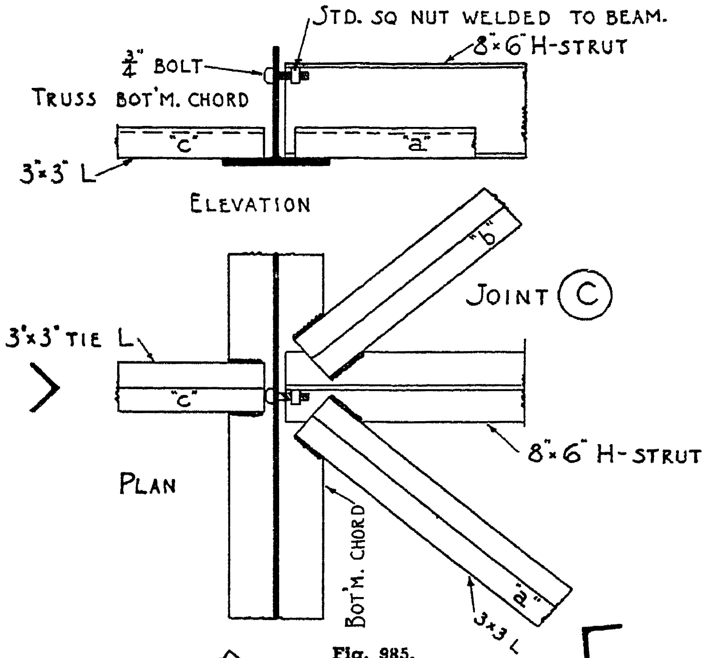


Fig. 985.

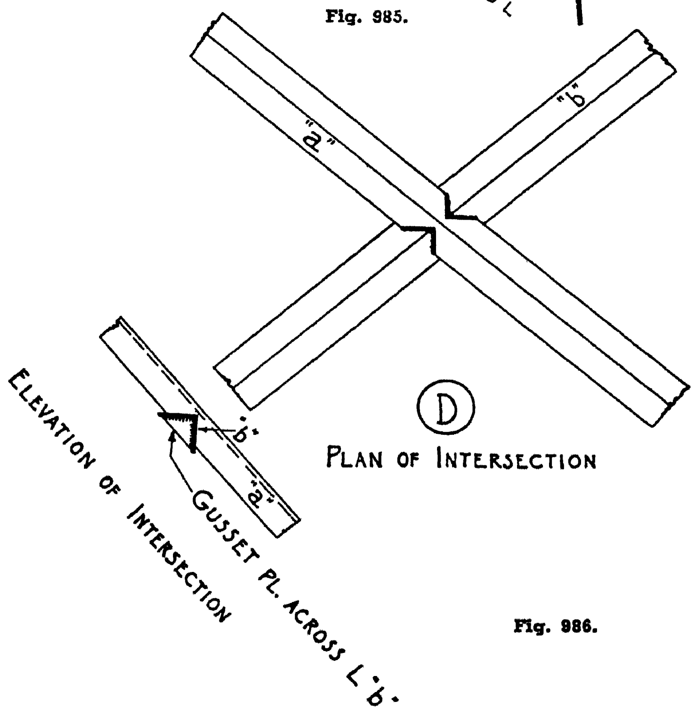
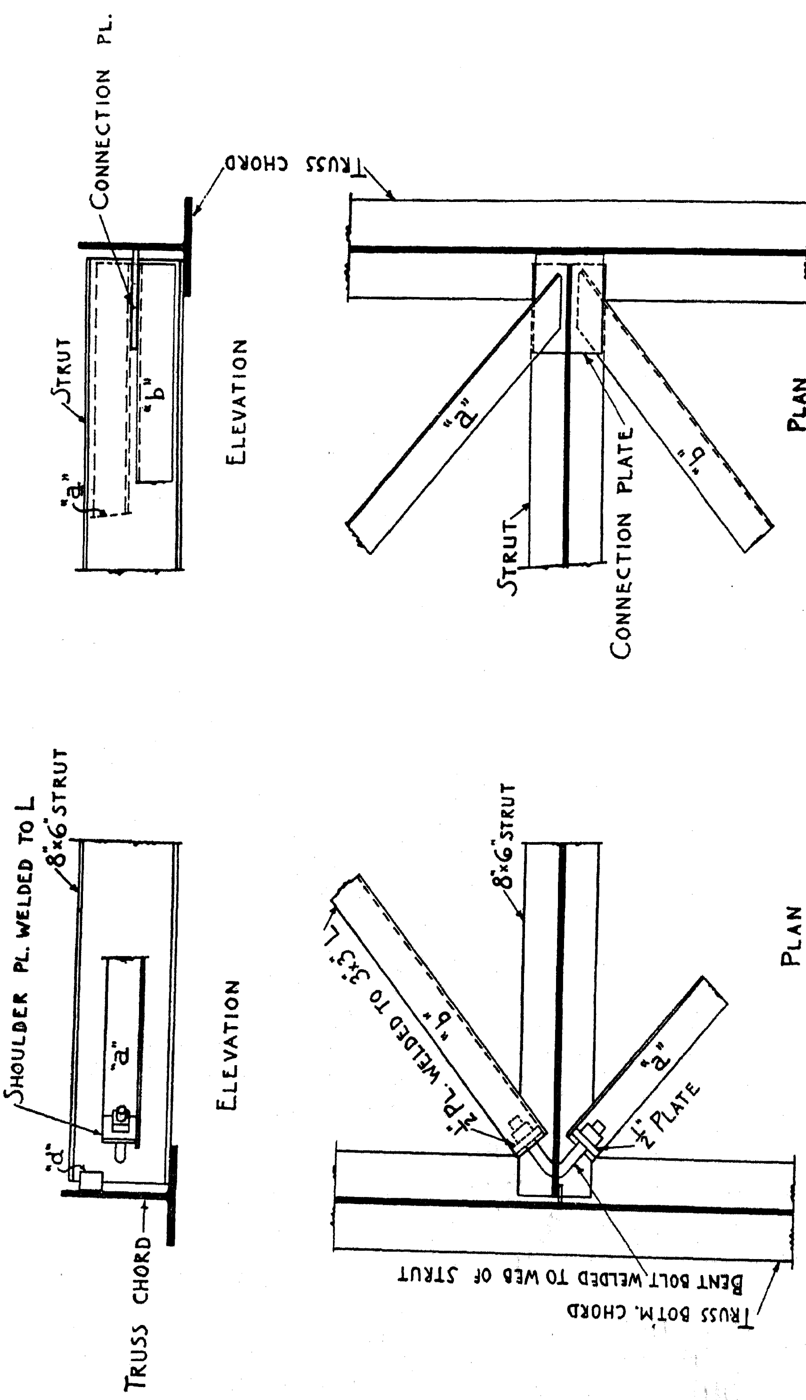


Fig. 986.



CONNECTION PL.
TRUSS CHORD
STRUT
"a"
"b"
ELEVATION
"a"
"b"
STRUT
CONNECTION PLATE
PLAN
SHOULDER PL. WELDED TO L
8"x6" STRUT
"a"
"a"
TRUSS CHORD
ELEVATION
8"x6" STRUT
"b"
"a"
1/2" PL. WELDED TO 3x3" L
1/2" PLATE
BENT BOLT WELDED TO WEB OF STRUT
TRUSS BOTM. CHORD
PLAN

Fig. 987.

plate welded to both legs, perpendicular to the angle's axis, forming a shoulder against which to turn up the nuts of the bent bolt. The diagonals are sprung by each other at their intersection. If there is no truss vertical adjacent to the strut to which the top of the strut may be secured, a small plate *d* may be used to stay the top of the strut against tipping because of the pull of the diagonals.

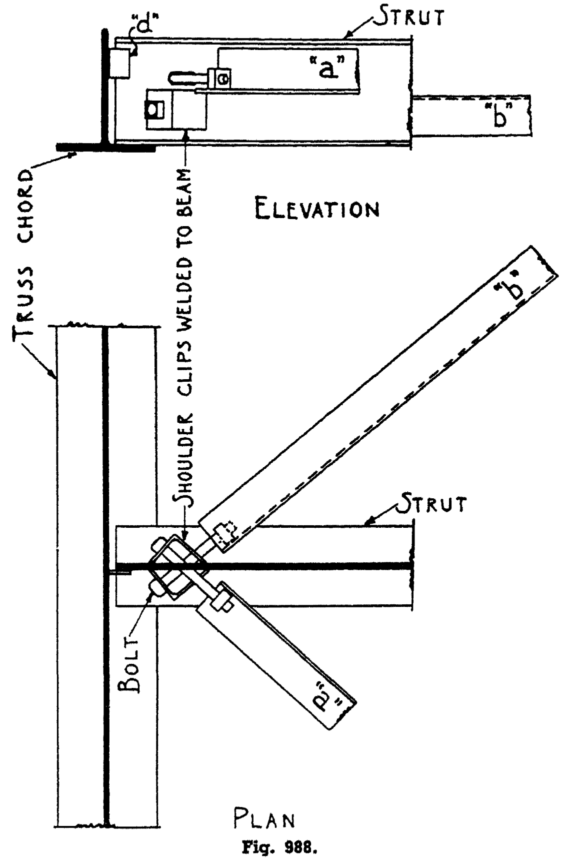


Fig. 988.

As it is sufficient to adjust one end of a diagonal, the other end can be welded in fixed position. A connection plate may be placed across the web of the strut, Fig. 987, in a slot made in the strut's web and welded to the beam, or two plates may be used welded to the beam on each side of the web. The diagonals are welded to this connection plate. The plate is shown projecting up to the web of the bottom chord. It is welded to the chord thus transferring the chord stress directly.

The arrangement shown in Fig. 988 is the same as the previous one except that two straight bolts placed at different levels are used instead of a bent one. The bolt heads rest against shoulder clips welded to the web of the strut.

Steel Plate Floors.—The construction of steel plate floors for office buildings, industrial buildings, warehouses and bridges consists of 3", 4", 5" or other rolled I-beams of whatever depth is found necessary, spaced approximately 24 inches apart and spanning from girder to girder of the structural steel framework of the building. On top of these beams are laid continuous steel plates $\frac{3}{16}$" or $\frac{1}{4}$" in thickness. The width of these plates should be such that when laid the longitudinal joints of the adjacent plates will occur directly over and in line with the webs of the supporting beams. The width of these plates may be such that they may span several of these beams. The plates are usually secured to the tops of the upper beam flanges by plug welds.

BATTLEDECK STEEL FLOOR CONSTRUCTION

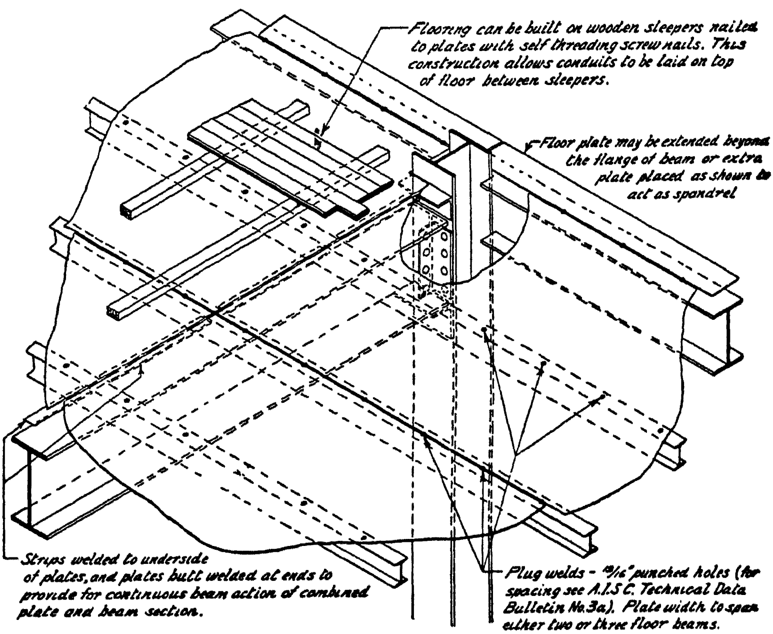


Fig. 989.

When the welding is done manually holes of about $\frac{13}{16}$" diameter should be punched in the plates at intervals of 12 inches to receive the plug welds. Along the edges of the plates half holes are punched which should match with half holes of butting edge of the adjacent plate. The ends of the plates should be spaced about $\frac{1}{4}$" apart and intermittently welded together with 2" welds. These transverse joints should be backed up with a small angle placed between the beams and to which the ends of the plates are welded. The sketch, Fig. 989, offers graphic description of this construction.

The punching of the plates can be eliminated when carbon arc welding is employed. The carbon arc will fuse the plate metal directly into the flange of the supporting beams. Automatic or semi-automatic welding equipment may be used for this work.

The result of welding the plates to the top of the flanges of the supporting beams is a built-up T section with the plates acting as the upper flange and the beam acting as the vertical part of the T. The neutral axis of the combined T section will be close to the top flange of the beam and when the lower flange of the beam is stressed to 18,000 lbs. per sq. in., the plates and top flange will have a stress of only 3,000 to 4,000 lbs. per sq. in.

With this type of floor construction there is generated a solid steel deck which will act as a girder to prevent any torsional distortion of the building when subjected to wind or seismic forces. It enables the engineer to select that part of the structure which is to carry the wind stresses to the foundations and be assured that the deck flooring will deliver the stresses to the most rigid part of the vertical frame. The floor construction can be carried out into the walls to provide spandrel construction to support the outside walls. It will also provide a working floor for other trades and in many cases eliminate the necessity of temporary planked floors.

A welded steel plate floor of the construction described previously, consisting of 3″ 5.7-lb. I-beams spaced 24″ centers and $\frac{3}{16}$″ plates, will carry a total load of 85 lbs. per sq. ft. on a 15-foot span, with a deflection of .235″. The weight of the steel work including beams and plates for this floor will be 10.5 lbs. per sq. ft.

It is possible to provide any form of treatment for the top surface of welded steel plate floors. Either mastic finish, linoleum, cork tile or wood flooring may be used. The latter can be applied economically by nailing wooden sleepers with self-threading screw nails to the steel plate, which has been previously drilled to receive the screw nails. The finished wood flooring can then be secured to these sleepers. This construction allows conduits to be laid on top of the steel plate floor between the wood sleepers.

Swimming Tanks.—Arc welded design of steel swimming tanks offers many advantages over riveted design. With use of arc welding an absolutely water-tight tank is assured without caulking. Punching of plates and structural members is eliminated. Connection angles required by riveted design are also eliminated.

Though size and capacities of swimming tanks vary, the description of one of many of arc welded design will give a clear idea of the construction. A description of the arc-welded swimming tank in the building of a nationally known athletic club, is given below. Fig. 990 shows a view of this tank.

This tank is supported at the third floor by twelve steel girders which carry longitudinal 7-inch I-beams spaced 2 feet apart. The $\frac{3}{8}$-inch floor plates, which extend 9 inches beyond the bottom of the wall plates, are tack welded to the beam; the joints are made on beam flanges and arc welded continuously. The intersection of floor and wall plates is arc welded continuously on both sides of the

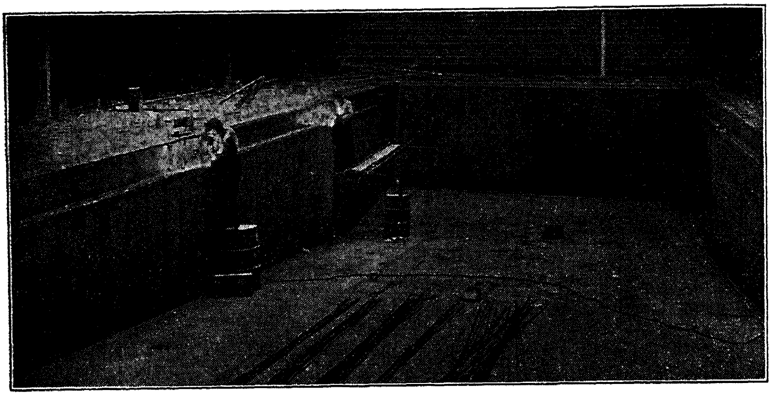


Fig. 990. Interior view of arc-welded swimming tank.

wall plates. The wall plates are reinforced by 8-inch channels spaced 2 feet apart, tack welded to the plates and welded at the bottom to the floor plates. All wall plate joints are made on channel flanges and arc welded continuously. At tank corners, the wall plates are arc-welded continuously to vertical corner angles. The bottoms of the angles are arc welded to the floor plates. The top of the wall plate is stiffened by a continuous horizontal channel and angle strutted to adjacent columns designed for the resulting thrust. The drain box is arc welded to the floor plates; all inlet and outlet pipes are arc welded to the floor or walls of the tank.

The wall plates were reinforced by channels, arc welded in shop before shipping; the balance of the work was laid out in the field and tack welded as erection progressed. The welding of the tank was then executed in one operation. After the water test, which proved the bare steel tank to be absolutely watertight, 3/8-inch rods were laid about 4 feet apart, both longitudinally and transversely and tack welded to the floor and walls of the tank, and to each other. To the rods was secured a 4" x 4" No. 11 wire mesh. This completed the welding operations. The inside of the tank was then coated with 1½-inch gunite retained by the wire mesh. The 1¼-inch tile finish and backing were then applied directly to the gunite.

Additions and Alterations.—Many additions or new structures have been joined to existing structures by arc welding. In fact, this was one of the first applications of arc welding to building construction. Many economies result from its use in this work.

Because arc welding is quiet, tenants in the existing building are undisturbed. In connecting beams of the new structure to the existing columns only a small amount of fire-proofing need be removed from the face of the columns. To rivet such a connection both faces of the column must be uncovered to permit drilling and riveting Fig. 991 shows an arc-welded connection to an existing column. This connection was made by bolting two 4" x ½" plates to the end of the beam. The holes in the beam webs were slotted horizontally, per-

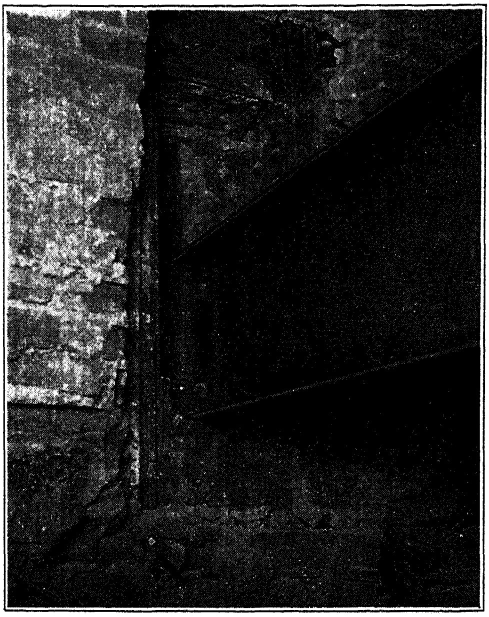


Fig. 991. Arc-welded connection of beam to existing column.

mitting the plates to be moved into close contact with the original columns while being held in position by the bolts. Plates were then arc welded to the webs of the new beams and to the original columns.

Connecting the end bay purlins of a mill building to the frame of an existing structure is most easily and economically solved by an arc-welded design. The conditions of a typical case are depicted in Fig. 992. The 18″ I-beam in the end wall of the existing building is shown, supported by its columns; the row of sloping purlins is to carry the roof of a new structure. These new purlins are to be attached to the existing 18″ I-beam.

The eaves strut of the new building, consisting of a beam and a sash angle, is framed to the existing column, a new seat, welded to the column, having been provided. In order to allow the wall sash to extend uninterruptedly by the face of the columns, it is customary to locate the vertical leg of the sash angle about 4″ out from the column face. If the sash angle is riveted to the beam, the horizontal leg of the angle must be long enough to permit the beam gauge and that of the angle to register. If the sash angle is welded, no matching of gauges is necessary and, consequently, a smaller sash angle, as shown in Fig. 993, may be employed.

The detail, Fig. 994, shows the connection of purlin *a* to the 18″ beam. A channel hanger is field welded to the bottom flange of the beam. This hanger carries two angle clips, shop welded at the proper slope and at the right level, to receive the purlin.

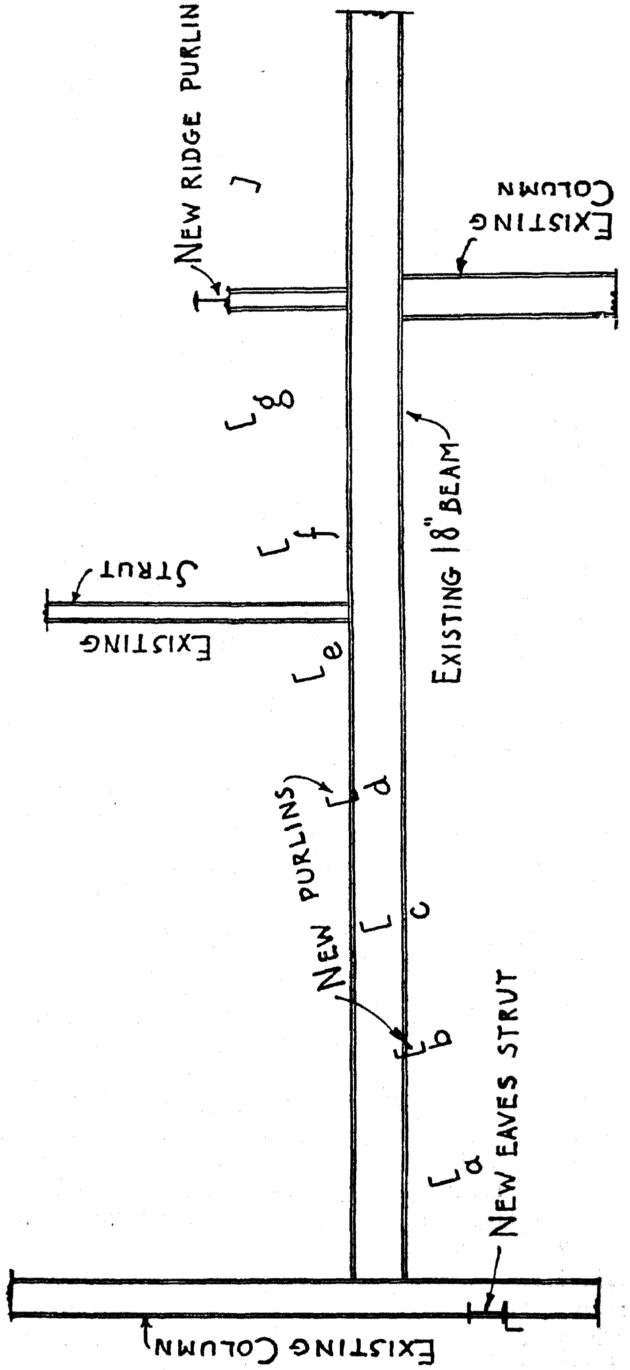

NEW RIDGE PURLIN
j
EXISTING COLUMN
g
EXISTING 18" BEAM
f
EXISTING STRUT
e
d
NEW PURLINS
c
b
NEW EAVES STRUT
a
EXISTING COLUMN

Fig. 992.

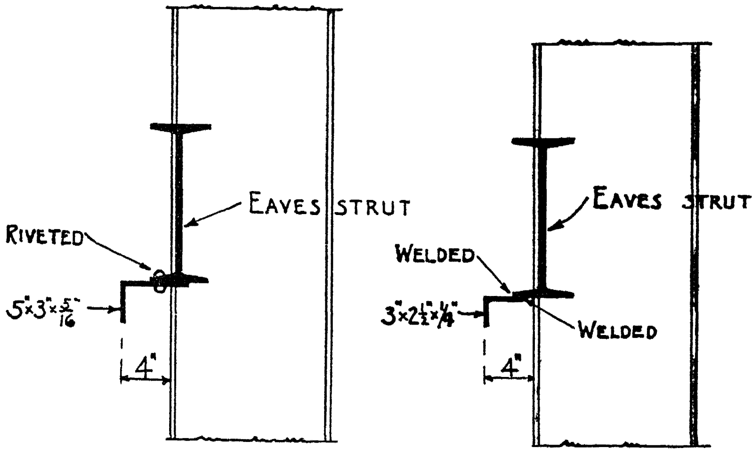


Fig. 993.

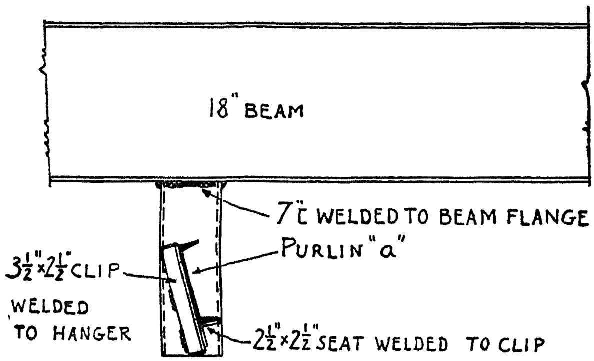


Fig. 994.

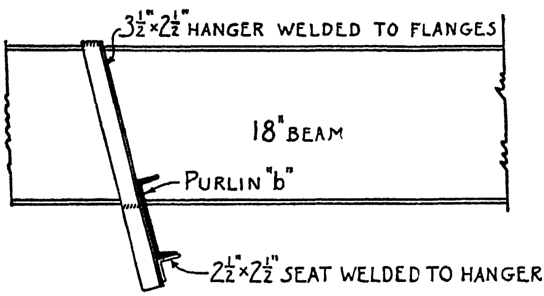


Fig. 995.

Two different ways of securing purlin *b* to the beam are shown in Figs. 995 and 996. In Fig. 995, the seat angle is shop welded to a hanger angle. This hanger is field welded to the top and bottom

flange edges of the beam at the proper slope. In Fig. 996, a detail similar to that shown in Fig. 994 is used. Fig. 997 shows a connection for purlin c which frames directly to the web; the detail is the same as shown in Fig. 994, omitting the hanger.

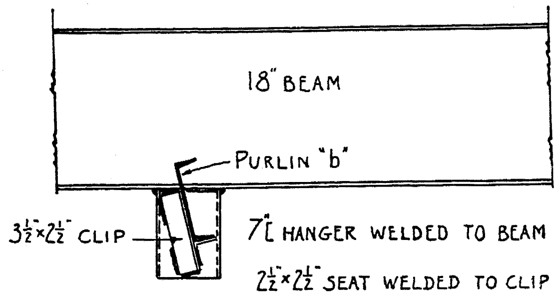


Fig. 996.

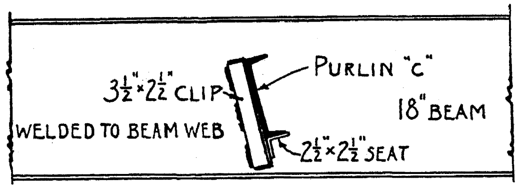


Fig. 997.

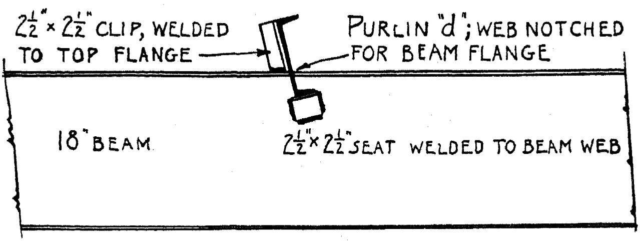


Fig. 998.

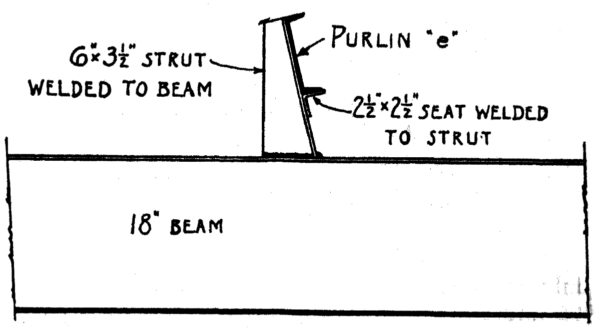


Fig. 999.

The connection of purlin *d* is shown in Fig. 998. This connection also requires two clip angles, one forming a seat for the bottom flange of the purlin while the other one, riding on the top flange of the beam, stays the purlin's web. The purlin is notched to clear the flange of the I-beam. Purlin *e* is carried by a chair, Fig. 999, made of two angles, one acting as a strut and the other as a seat.

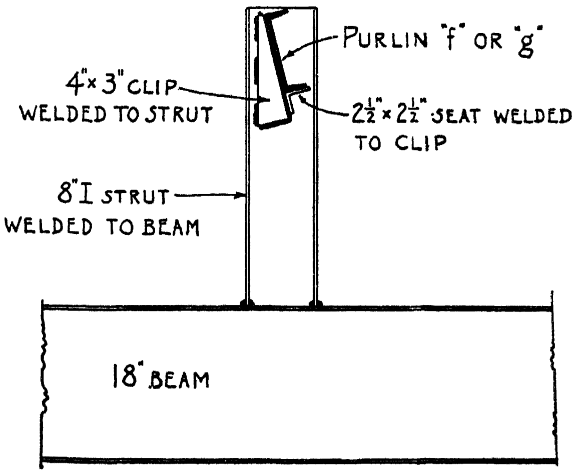


Fig. 1000.

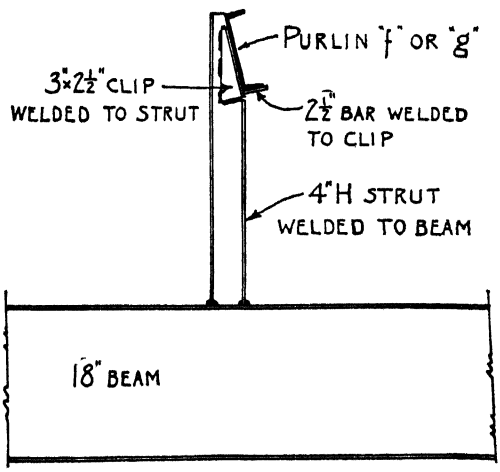


Fig. 1001.

Figs. 1000, 1001 and 1002 illustrate methods of securing purlins to the beam when they are located as shown in Fig. 992 in positions *f* and *g*.

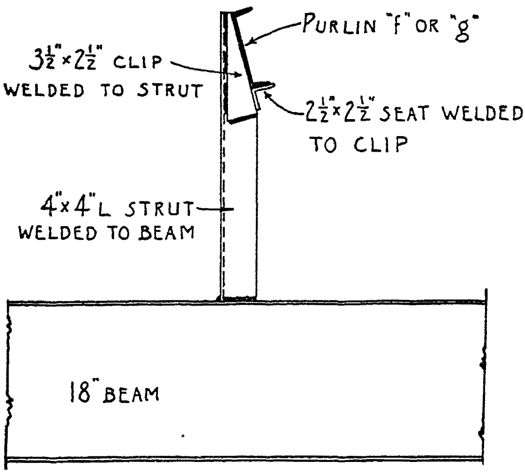


Fig. 1002.

In Fig. 1000, two clips welded to an I-beam strut form the purlin's seat. In Fig. 1001, the top of an H-strut is bevel-cut to the slope of the purlin's web, a clip angle and a bar forming the seat. In Fig. 1002, the seat clips are shown attached to an angle strut.

In the case of the ridge purlin's connection, Fig. 1003, the purlin rests on a cap plate welded to the top of the post. If desired, a thin bent plate may be tack welded in the shop to the ridge purlin forming a convenient seat for the metal decking.

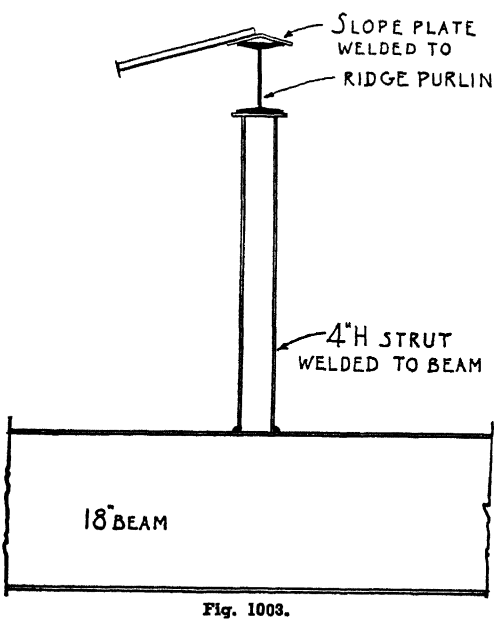


Fig. 1003.

Steel Frame Houses.—The growing use of steel instead of lumber for framing of residential dwellings has recently been accelerated by the application of arc welding to this class of construction. As in other classes of steel structures arc-welded design eliminates practically all punching and bolting. House frames of this design erected today prove the economy of arc welding instead of bolting.

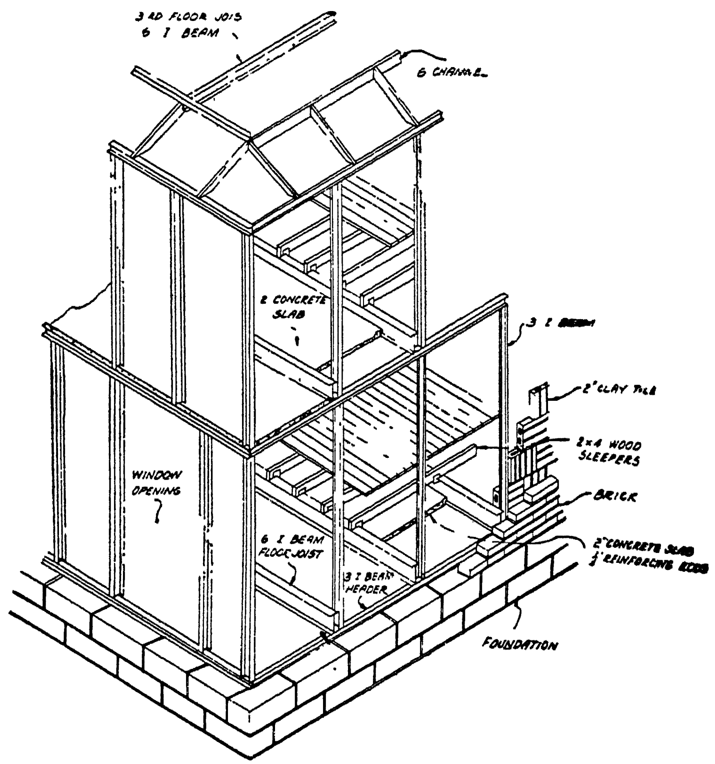


Fig. 1004.

One type of arc welded design eliminates all shop fabrication. The steel cut to correct lengths is delivered direct from warehouse or mill to the site. Such a structure, designed by George Howard Burrows, Architect, Cleveland, Ohio, has been erected at practically the same cost as a wood frame dwelling. The Burrows design calls for 3-inch channels as studs, 6-inch I-beams as floor joists and 3-inch I-beams as sills and headers. The isometric sketch, Fig. 1004, portrays the design.

Another arc-welded design divides the framework for the walls and load bracing partitions into sections or panels one story high and of such width as to permit easy handling in the field. Placing a first-floor panel in construction of a 12-room steel-frame residence

Fig. 1005. Placing a shop-welded panel in erection of 12-room residence.

is shown in Fig. 1005. The panels in this type of design are shop-fabricated by welding. They are generally provided with clip angles punched for temporary bolting during erection prior to field welding. Fig. 1006 illustrates field welding by the electric arc process.

With this type of design, field welding of wall and partition framing is reduced to a minimum. Some of the details of the design are illustrated in Fig. 1007.

Other applications of welded steel houses are shown on Pages 804 to 808.

Fig. 1006. Field welding of steel frame of 12-room residence.

Fig. 1007. Residence framing partially shop welded and erected in sections or panels.

Cost Factors.—It must be kept in mind that in structural welding, where welding is done both in shop and field, many factors enter into the cost and that, therefore, the economy of welded construction depends not only on the process itself but upon the methods of fabrication, handling in shop and field; these in turn depending on equipment and personnel available.

A shop equipped with spacers, edge planers, gang drills, etc., with a force of men accustomed to use those machines effectively will use different methods of fabrication than another shop equipped only with shears, single punches and drills and a rudimentary riveting outfit. Similarly, a shop well equipped with transfer cranes, with jibs or gantries to handle and turn the work over and with a personnel experienced in arc welding and automatic flame-cutting will handle work quite differently than a shop less completely equipped and obliged to expand its welding staff every time it faces a job above average size.

One shop will cut plates with a shear while another one cuts them with a flame-cutter; one shop will true the edge of web plates with an edge planer while another will use a fillet weld and a grinder.

Fig. 1008 shows a section through a riveted girder in which it is desired that the web bear intimately against the top cover plate. This girder may be a building girder carrying a very heavy distributed load or several columns; it may be a heavy crane girder

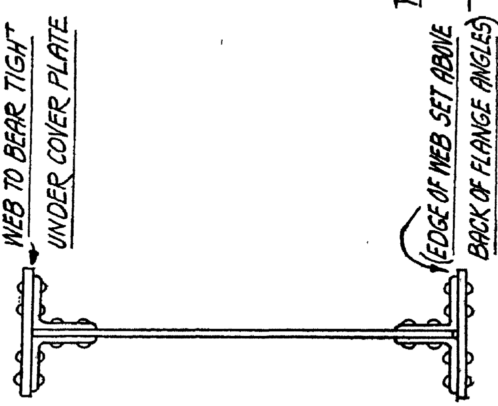


Fig. 1008.

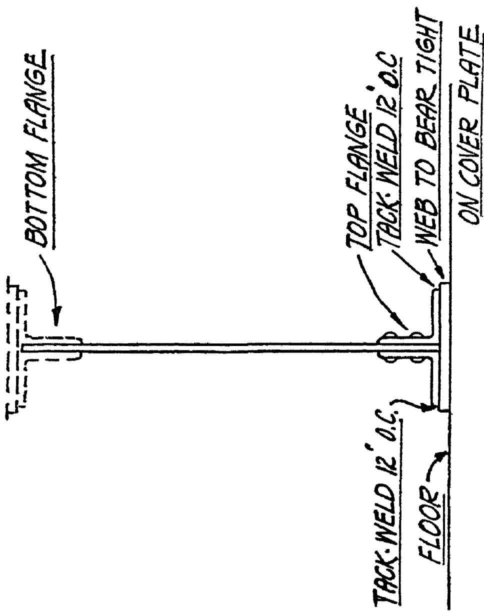


Fig. 1009.

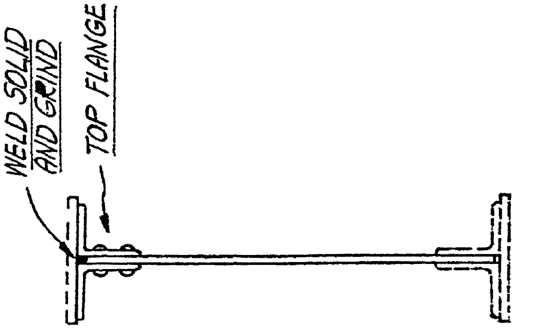


Fig. 1010.

in a factory or a railroad deck girder. It is realized, of course, that sheared plate edges are not true enough to give a solid, dependable bearing edge. As a consequence, in riveted practice, such plates are set back from the back of the flange angles as illustrated in Fig. 1008 bottom flange. One shop has an edge planer: it may elect to set one edge of the web plate against the planer and machine it true. This done, the girder will be assembled upside down (Fig. 1009), the top flange on the shop floor, the machined edge of the web bearing on the flange plate and the angles, first assembled to the web, will now be tack-welded to the flange after which the assembly will be taken to the riveters.

Another shop will accomplish the same result by assembling the top flange angles (Fig. 1010), riveting them together, then arc welding the gap between the back of the angles and grinding the top of the weld flush with the back of the angles after which the top flange will be assembled to the angles in the usual way.

It will be noted that if there are only a few spots in the length of the girder where bearing of the web against the under side of the top flange plate is necessary—such as under columns resting on the girder—there is no advantage in planning the full length of the web.

Similarly, if only a few girders are involved, it would likely be cheaper to use welding and grinding than to set up a large planer to do the work.

It follows that cost comparisons between various means and methods of fabrication depend upon the set-up of the individual shop and that the cost comparisons must be made by the plant operators.

It is essential that these men make themselves thoroughly familiar with all the advantages of arc welding because this process does furnish a means of cutting fabrication costs in countless cases.

Another factor that has a noticeable effect on welding costs is that of drawings—both design and shop drawings.

It is common experience among fabricators to receive framing plans which indicate girders, columns, beams, etc., accompanied by such a note as this one: "Girders may be welded." Or "Column details are to be arc welded." Nothing definite is indicated regarding the size and the amount of welding desired. It is evident that, when the estimators price the job, they must play safe: the possible welding that might be demanded by the designer is assumed—not the amount that is actually needed. Later on, the girders or columns will be detailed with the correct welding; even if the designers accept the details as made, the cost to the owner of the structure will still be that figured into the job by the estimators.

The point made here is not that every piece should be detailed by the designer;—details should be made by the detailers. But the designers should indicate clearly by notes on the drawings and by suitable items in their specifications what type of welding they will expect, what they will require for girder welding, for columns and for beam to column connections. Items recurring in considerable numbers should be plainly shown on the drawings.

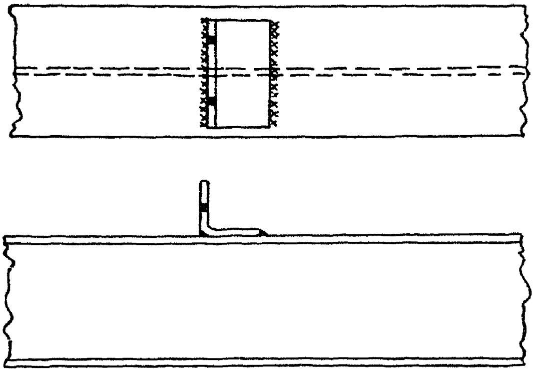


Fig. 1014.

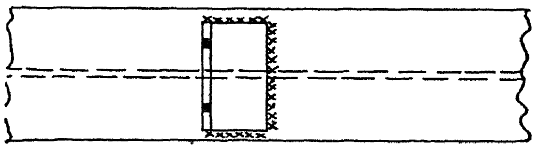


Fig. 1013.

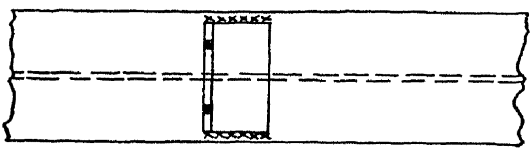


Fig. 1012.

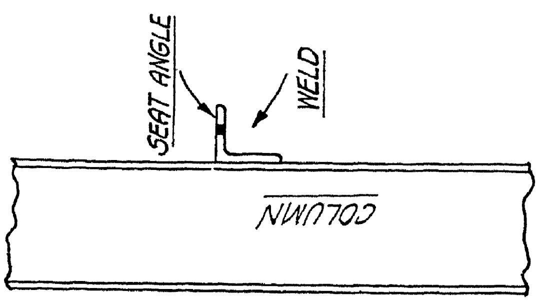


Fig. 1011.

A common detail received in the shops is shown in Fig. 1011. The load is not indicated; neither is the position nor the size of fillet. The shop may weld the angle as shown in Fig. 1012 or in Fig. 1013, or it might weld it the right way, Fig. 1014—but, in any case, the angle has been welded as called for by the detailer's sketch, Fig. 1011. It takes very little time to actually show what is really required.

Another detail often received in the shops is shown in Fig. 1015. The column may be an 8″ H with a sole plate ¾″ thick or a 14″ column with a base slab 4″ thick, but the detailer's note is the same: "Weld." If there is any excuse for such a note in the case of a light column and base, there is none in the case of heavy ones. There is usually, then, considerable disparity between the thickness of the column section and that of the slab base. In such cases, the welding requires special care and it should be shown clearly on the shop details.

In Fig. 1015, note that the arrows point to both the flange and to the web. It will be observed that base plates 2″ thick or less are not usually milled, so that there is a possibility of more or less accurate bearing of the web on the base; consequently the conditions may warrant that the web be welded to the base. Bases heavier than 2″ are milled; the bearing of the column web on the plate is positive. There is no good reason in such cases to weld the web to the base. Even if there is bending in the column—in either direction—the welds connecting the flanges to the base would have to be torn off before an appreciable stress could be developed in the welds connecting the web to the base plate.

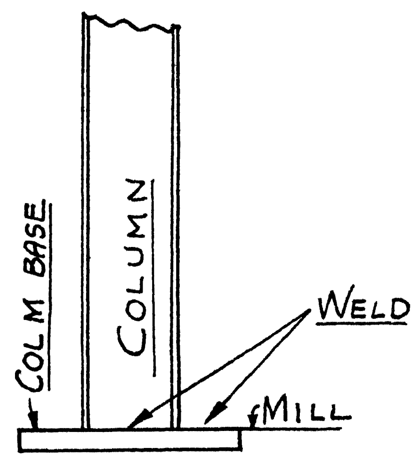


Fig. 1015.

An important point to bear in mind when designing welded structures is to keep the amount of welding to the required economical amount.

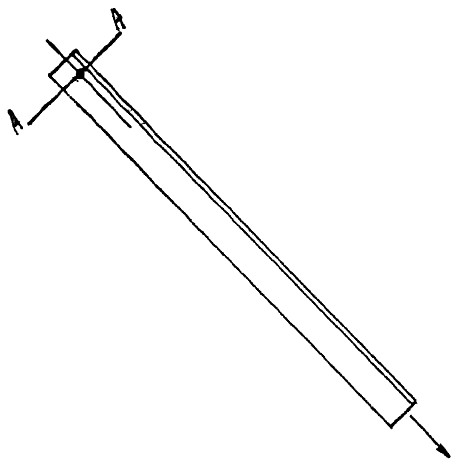


Fig. 1016.

In a riveted member, it is not of prime importance to keep the number of holes and of rivets down to the figured minimum. For example—Fig. 1016 shows a tension angle connected by a single rivet. The effective section of the angle across section AA is decreased by the diameter of the hole. In Fig. 1017, the same angle is connected by three rivets. The loss of section is no greater than

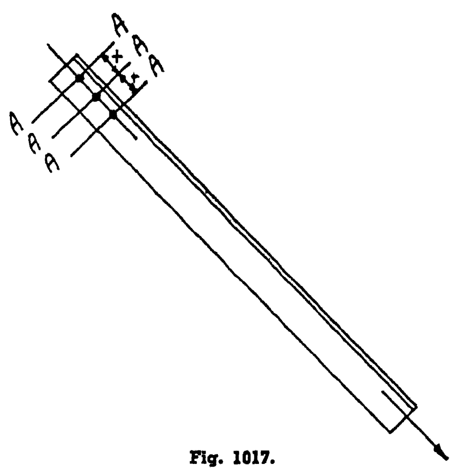


Fig. 1017.

in Fig. 1016 since the three holes are in line and spaced a distance x from each other. As a consequence, in riveted work, the custom exists of detailing connections for the full strength of the member connected whether this is needed or not. There is no particularly good reason for the practice and it should not be applied to welded work. While there is the excuse that, in riveted work, "it costs no

more to punch three holes than to punch one," it does cost more to drive three rivets than to drive one — and it certainly costs more to lay down twelve inches of 5/16" fillet than to lay down four — just three times as much.

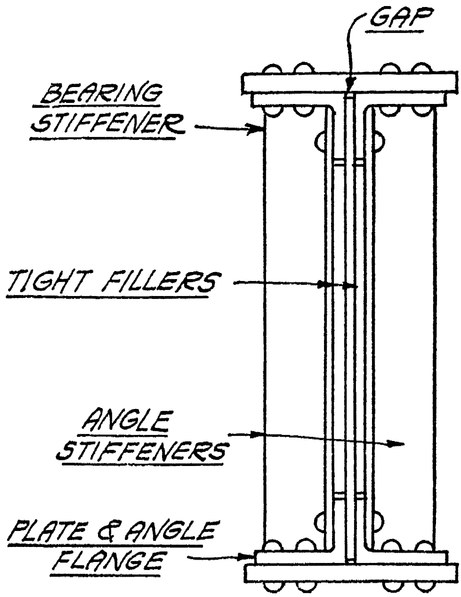


Fig. 1018.

In designing welded structures, the welding should develop the stresses, not the material; i.e., the stress should dictate the size of the welds.

Riveted work has developed its methods and practices from its own inherent nature. Welding has its own peculiarities and should logically establish practices that are in line with these peculiarities. It is not just a matter of copying riveting practices.

Consider, for instance, girder stiffeners. A bearing stiffener, in a riveted girder, needs a filler plate to make up for the thickness of the angles against the web, as shown in Fig. 1018. In a welded girder, Fig. 1019, no such fillers are needed because there are no angles. In Fig. 1018, the top of the stiffener is not connected to the flange; in Fig. 1019, it is welded to the flange.

The stiffener in Fig. 1018 is an angle, one leg of which is parallel to the girder's web and this leg may not be counted upon to transmit a concentrated load to the girder web according to bridge specifications and others. In Fig. 1019, all of the stiffener is perpendicular to the web and since it is direct connected to the flange, all of it may be counted upon for transmitting load to the web.

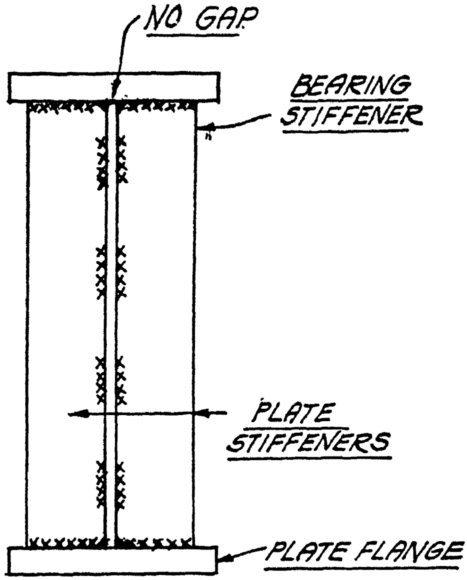


Fig. 1019.

The fact that the plate stiffener in Fig. 1019 is welded solid at both ends to the flanges makes it a column fully fixed at the ends. Advantage should be taken of this condition in designing welded stiffeners. The ones figured and shown in Fig. 834 and on pages following could then be materially reduced.

In Fig. 1018, the usual set-back of the web plate forms a gap which prevents direct transmission of stress to the web plate. In Fig. 1019, no such gap exists: consequently, at least a portion of any concentrated load is taken directly into the web. That much less needs to be figured as being carried by the stiffeners; this accounts for a further reduction in material.

Non-bearing stiffeners in a riveted girder, such as shown in Fig. 1020, must be attached to the web. In a welded girder, the ends of all stiffeners should be welded to the flanges (Fig. 1019), to square up the girder and hold it in place during the subsequent welding. Consequently very little welding of such non-bearing stiffeners to the girder web is needed since their only function is to hold in alignment the web which they straddle. Nevertheless, many a welded girder drawing comes to the shop showing non-bearing stiffeners full-welded to the girder web—a distinct waste of time and material.

In the shops, many a welder and many an inspector prides himself on "turning out a good job" by overwelding. The quarter inch fillet specified turns out to be full 3/8"; the two-pass 1/2" fillet called for on the drawings gauges almost 3/4" and the shop will draw the

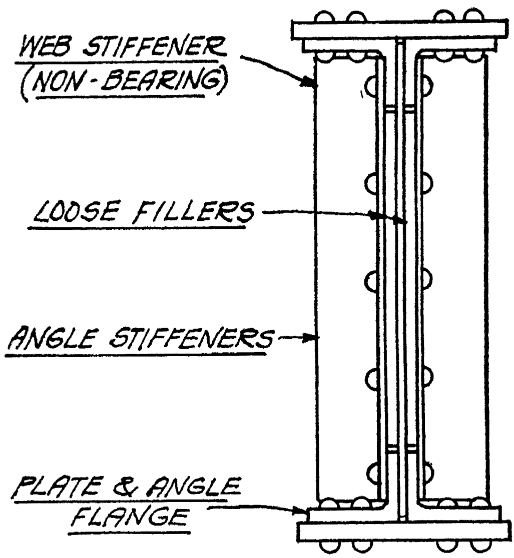


Fig. 1020.

engineer's attention to the fact that "he's getting his money's worth and then some." Now, it has been this engineer's business to make allowances for "the human element," for shrinkage and for all such factors as well as for the figured stresses in the connections at the time he was designing the job. Consequently, the shop should not feel that it is incumbent upon it to add welding to that shown on his drawings. To do so would indicate that the shop does not feel over-confident of the Engineer's proficiency in designing the welding or in the value of its own work. Overwelding should not be encouraged.

PART VIII

TYPICAL APPLICATIONS OF ARC WELDING IN MANUFACTURING, CONSTRUCTION AND MAINTENANCE

PART VIII

TYPICAL APPLICATIONS OF ARC WELDING IN MANUFACTURING, CONSTRUCTION AND MAINTENANCE

The use of arc welding as a manufacturing, construction and maintenance tool in practically every industry has resulted in widespread economies and product improvements. To attempt to describe or illustrate each particular type of application in every industry would require far more space than this volume affords. The brief descriptions and illustrations of a few of the present applications of arc welding which follow, merely indicate the possibilities of the process as applied to the work or products of the reader.

Aircraft

Practically every airplane factory uses arc welding for the production of certain parts and for the building and maintenance of shop equipment. Arc welded parts of the plane shown in Fig. 1022 include landing gear and engine mounts. The fuselage is assembled in arc welded jigs as shown in Fig. 1023. For procedure information on the welding of chromemoly steel such as used in plane construction, see Page 298.

Fig. 1021. Arc welding is used extensively in the construction of this flying fortress

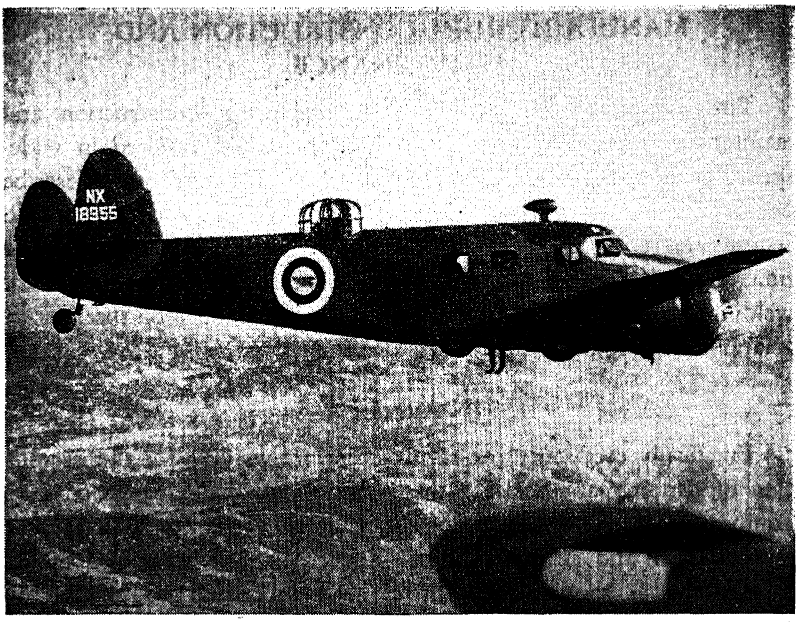


Fig. 1022. American-built bomber. Engine mounts and landing gear are arc welded.

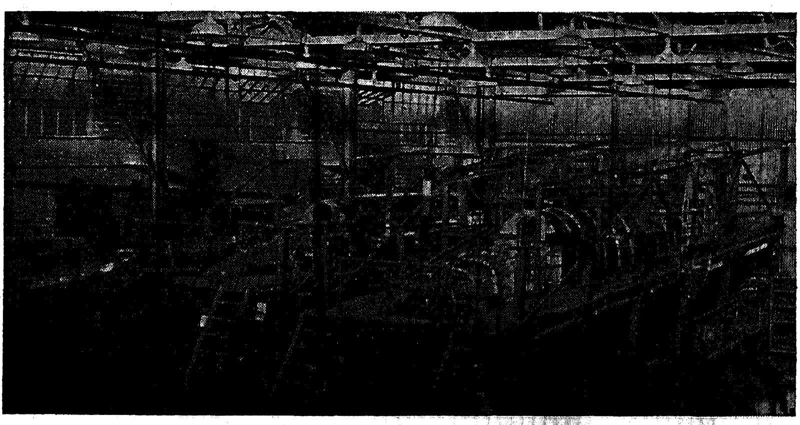


Fig. 1023. Arc welded fuselage jigs in a large Western plane factory used to build the plane shown in Fig. 1022.

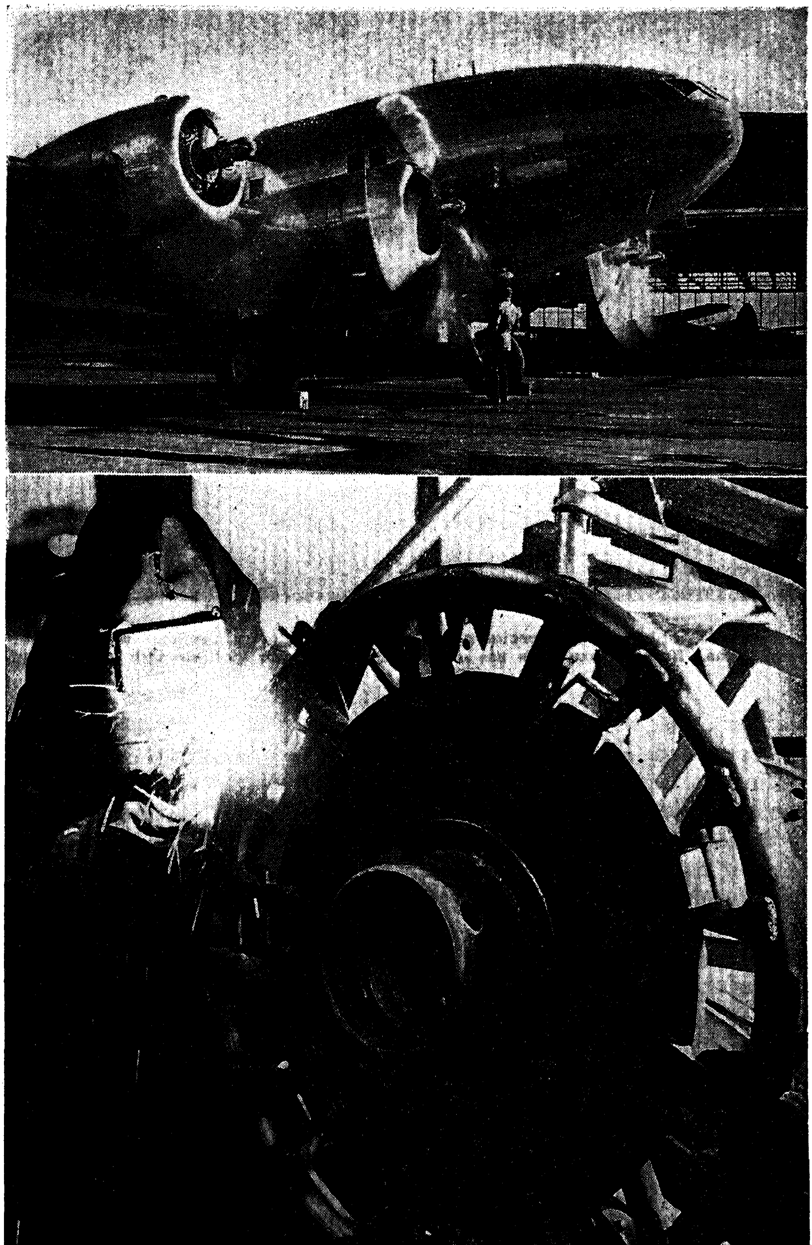


Fig. 1024. Welding a motor-mount for a Stratoliner, closeup of which is shown in the view at the top. The jig used for holding the mount is also of arc welded construction.

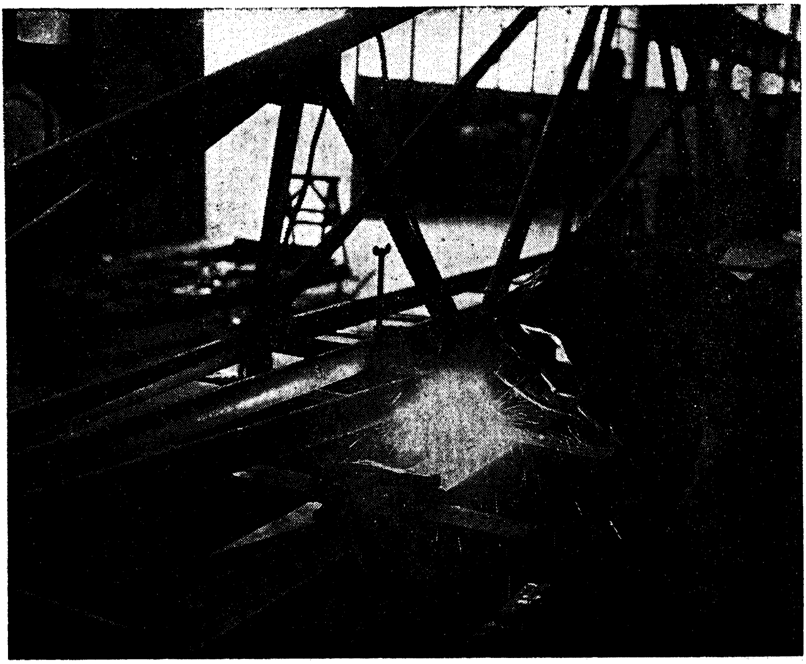


Fig. 1025. Fabricating a special frame used for picking up fuselages with an overhead crane. Note the extensive use of tubular members for high strength and rigidity.

Automotive Equipment

A large number of automotive parts are manufactured by means of electric arc welding. Many of these are produced by the automatic process.

The automatic carbon arc welding set-up shown in Fig. 1026 produces rear axle housings at a speed of 43 seconds each. These housings consist of two stampings clamped in a fixture and placed under the arcs. The two arcs are struck simultaneously and held for a second to secure proper penetration. The carriage motor then engages and the welding heads move in opposite directions to the ends of the housing. A weld closeup is shown in Fig. 1027.

At this point the arc is broken and the heads automatically return to their original position. The housing in the fixture is then rotated 180° and the opposite side of the housing welded in the same manner. Generally one man operates two machines and completes on an average of 53 units per hour.

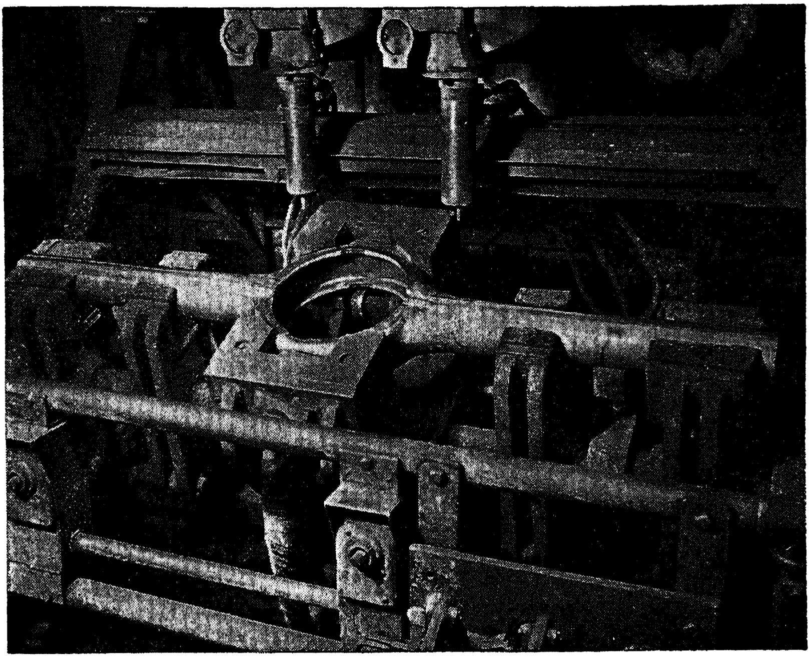


Fig. 1026. Setup for automatic welding of rear axle housing.

Tubular parts such as torque tubes, cross shafts, etc., are also produced economically by automatic arc welding. Tubular parts of welded construction are exceptionally strong, light and of uniform wall thickness. Torque tubes of welded construction vary in length from 48 to 66 inches. A typical setup for welding these parts is shown in Fig. 1028. This automatic carbon arc welding equipment includes beam-mounted carriages which are propelled along the overhead beam, carrying the arc over the work which is clamped over mandrels. The welding is done in one direction, the heads returning rapidly to the starting point after the weld is completed. Thickness of metal is $\frac{5}{32}$-inch. After welding, the tubes are upset. This setup saves 10% to 50% in materials cost, depending upon the type and design of tube. A display of tubes of many types is shown in Fig. 1029.

Frames for automobile starters and generators, consisting of formed $\frac{5}{16}$-inch plate, are butt welded with the automatic equipment shown in Fig. 1030. A total of 5½-inches of welding is required for each frame. Closeup of a completed frame is shown in the insert.

Automatic arc welding also plays an important part in the fabrication of mufflers. In Fig. 1031 is shown automatic welding machines in operation for welding louvred tubes to the inner shell of the muffler. The weld joins the tubes to the inner head or baffle plate of the muffler. The time for automatic welding approximately four lineal

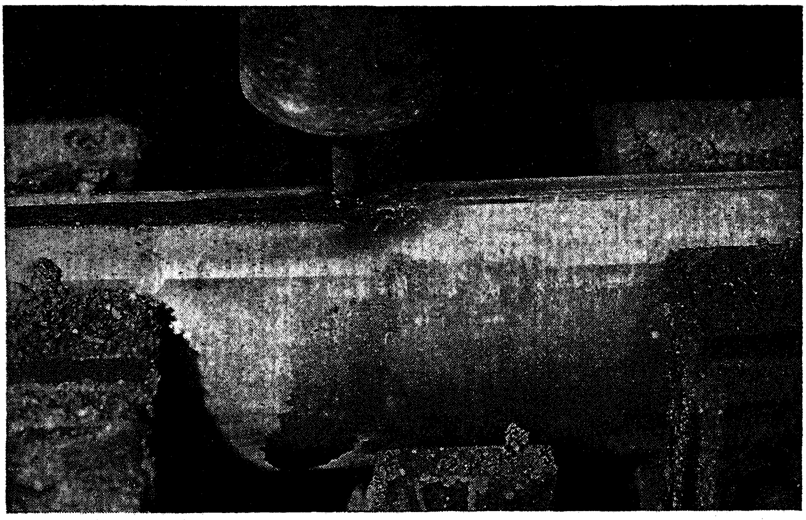


Fig. 1027. Closeup of weld in rear axle housing produced by automatic carbon arc.

inches on each of the tubes is two and one-half seconds. In this particular application, two such welds are made on each end of each muffler, making a total of four welds per muffler. Two men operating three automatic welders as shown produce 250 mufflers per hour.

There are numerous automotive parts whose fabrication requires a very small amount of welding. For this reason it is often more economical to weld them by the manual process. Some automotive parts are of such shape that they cannot be readily or economically set up for automatic welding, especially when the amount of welding required is very small. The manual process of arc welding is generally employed in such cases.

In addition to its use in the production of automotive parts, arc welding is used extensively in the assembly of automobile bodies. A typical application is shown in Fig. 1032. This view shows a steel top being removed from the special fixture after welding the rear panel. Closeup of the finished weld is shown in Fig. 1033. Changeover from spot welding and soldering in this case saved $3.00 per body and made the body stronger, safer and better looking. After welding, the excess weld metal is ground off and the joint is finished with a small amount of soldering in the conventional manner.

Other applications of arc welding in the fabrication, construction and maintenance of a wide variety of automotive equipment, are shown on the following pages.

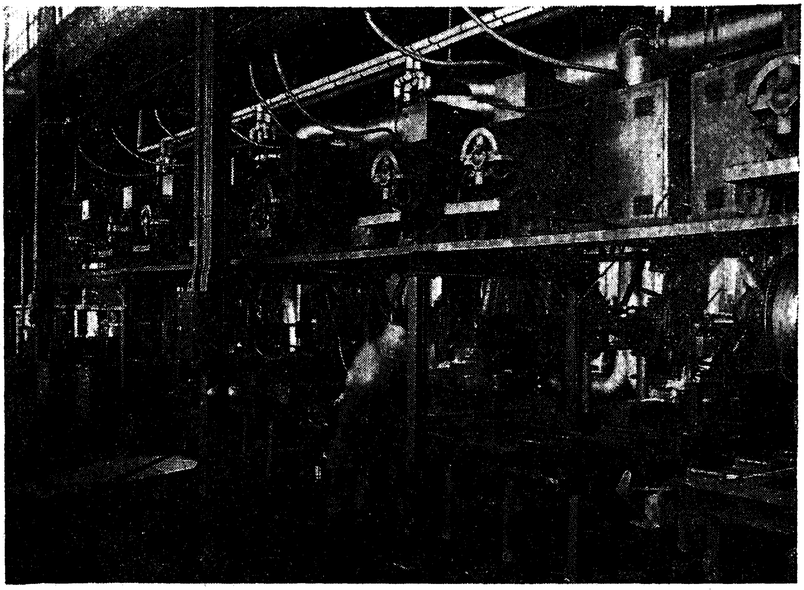


Fig. 1028. Production line scene showing automatic welding of torque tubes at speed of 2000 feet of tubes per hour.

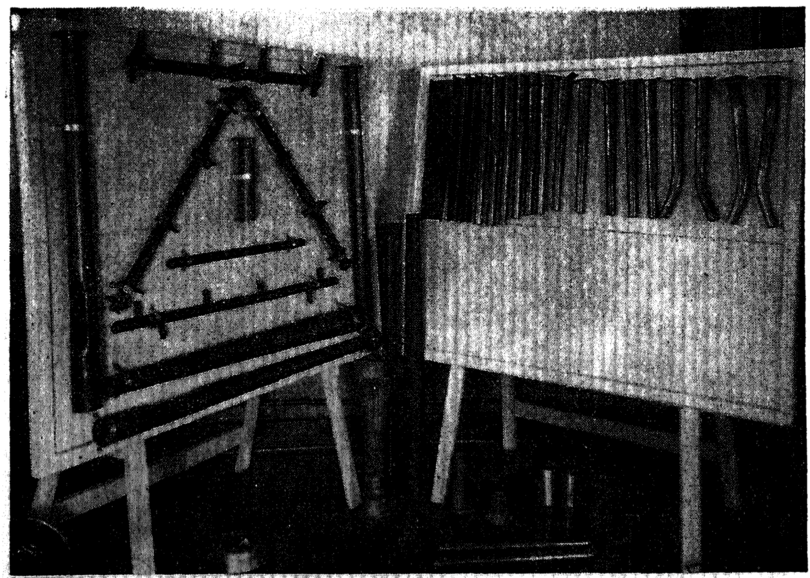


Fig. 1029. Display of tubular parts made of strip steel formed into tubes and automatically welded with a shielded carbon arc.

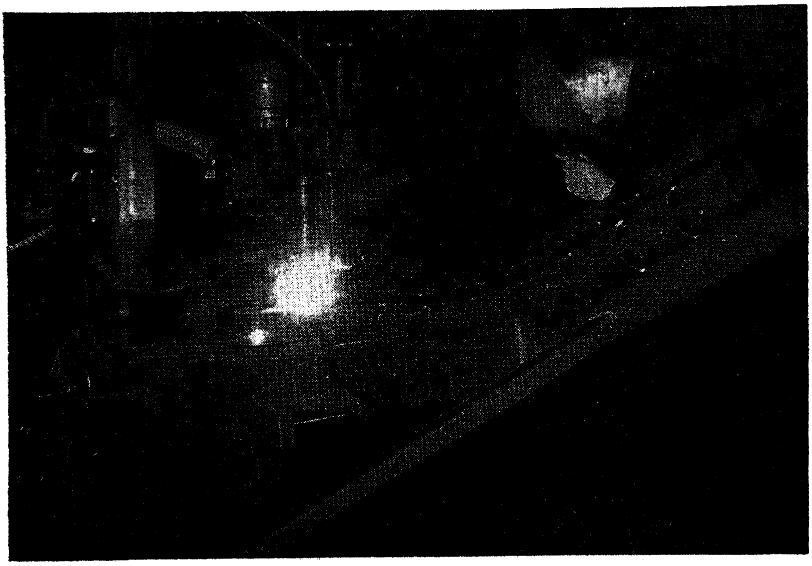


Fig. 1030. Automatic carbon arc welding of generator frames.

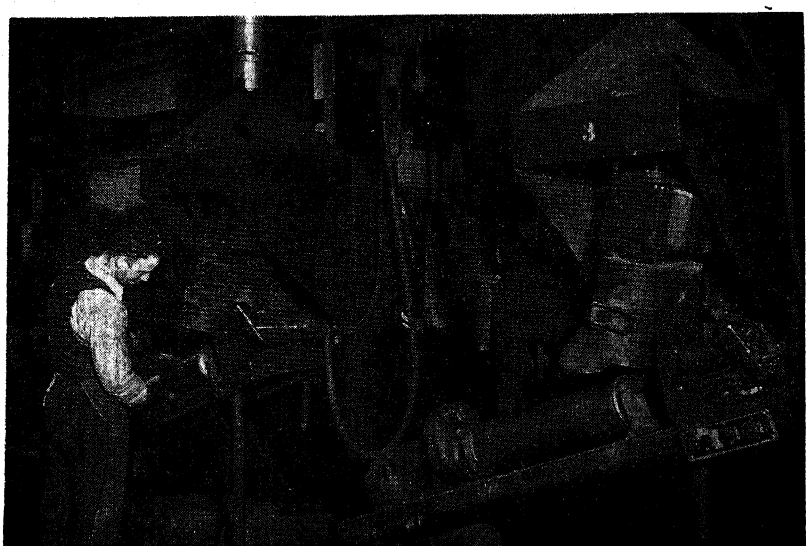


Fig. 1031. Automatic welding of mufflers.

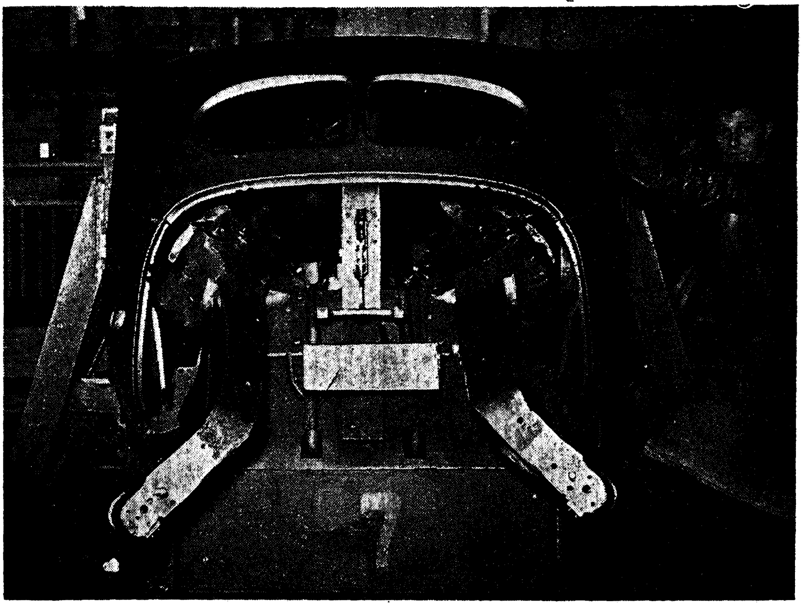


Fig. 1032. Automobile body top being removed from welding fixture.

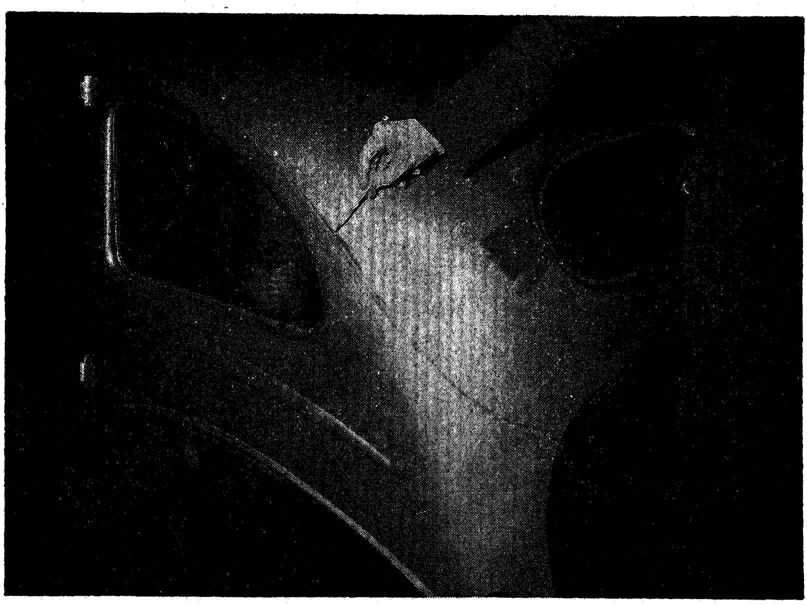


Fig. 1033. Completed rear panel weld before grinding.

Fig. 1034. All steel house trailer fabricated by arc welding. Chassis members are formed from 16 and 18 gauge steel. Assembly by arc welding employing jigs saves 30% of the cost of former fabrication methods.

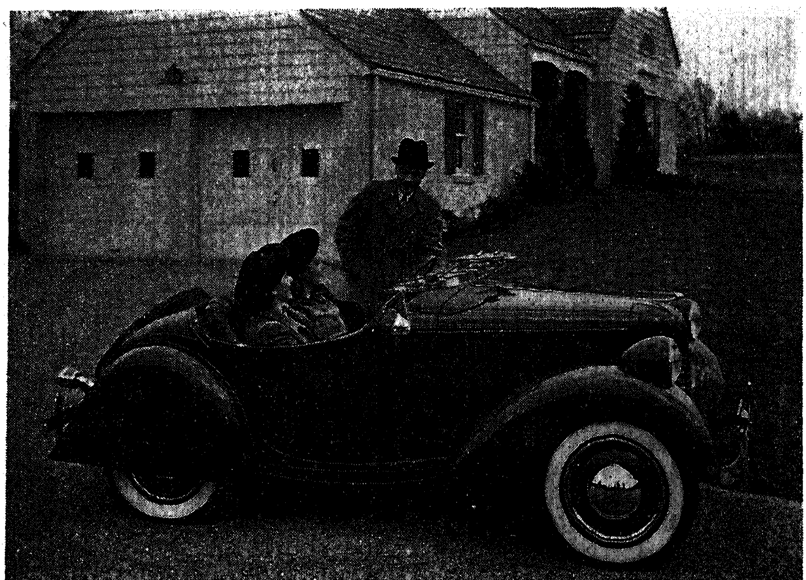


Fig. 1035. Arc welded construction is used extensively to provide strength and neat appearance in the body and chassis of this automobile.

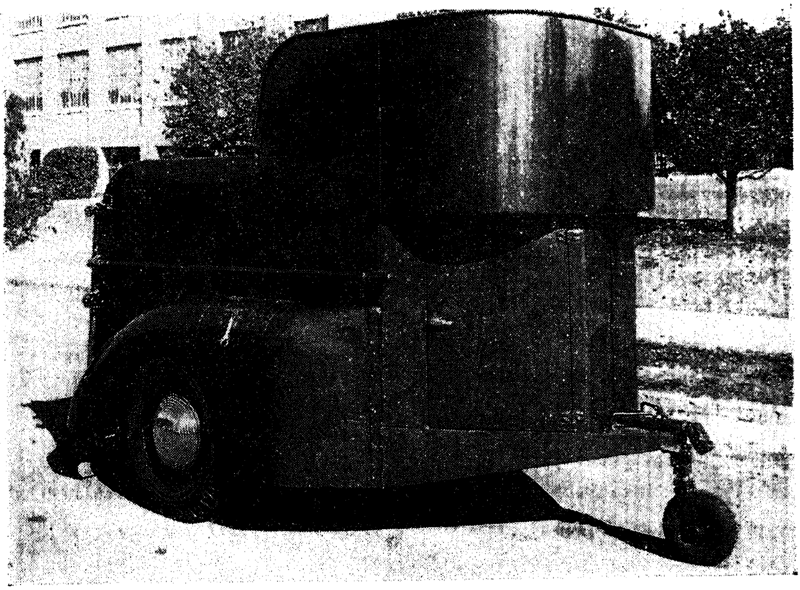


Fig. 1036. A special trailer of all welded steel construction. Replaces wood construction, saving 20% in cost.

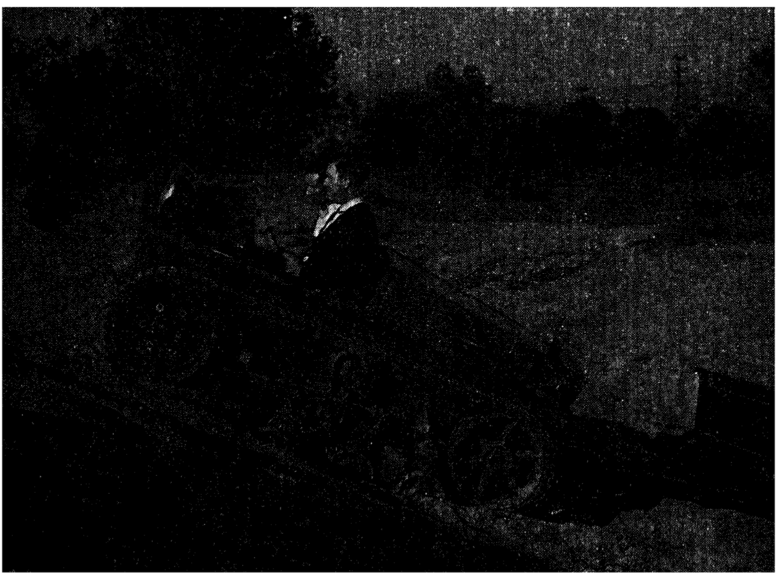


Fig. 1037. Special tractor used by the Army, features light weight, high speed and great rigidity through use of welding steel. Entire hull is water-tight.

Fig. 1038. Group of circus wagons of all welded steel construction.

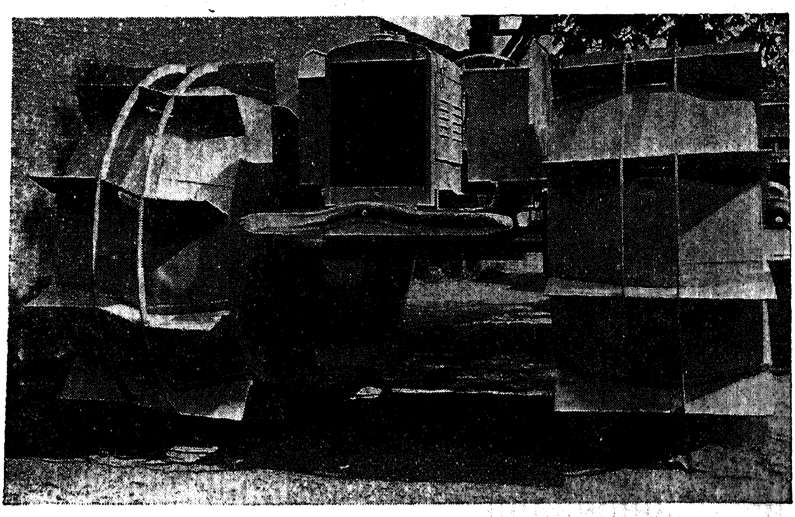


Fig. 1039. Marsh buggy used for transportation and exploration work by a large oil company. Welded steel wheels 7-ft. in diameter, 4-ft. wide, permit good traction on highway, in swamp or in water.

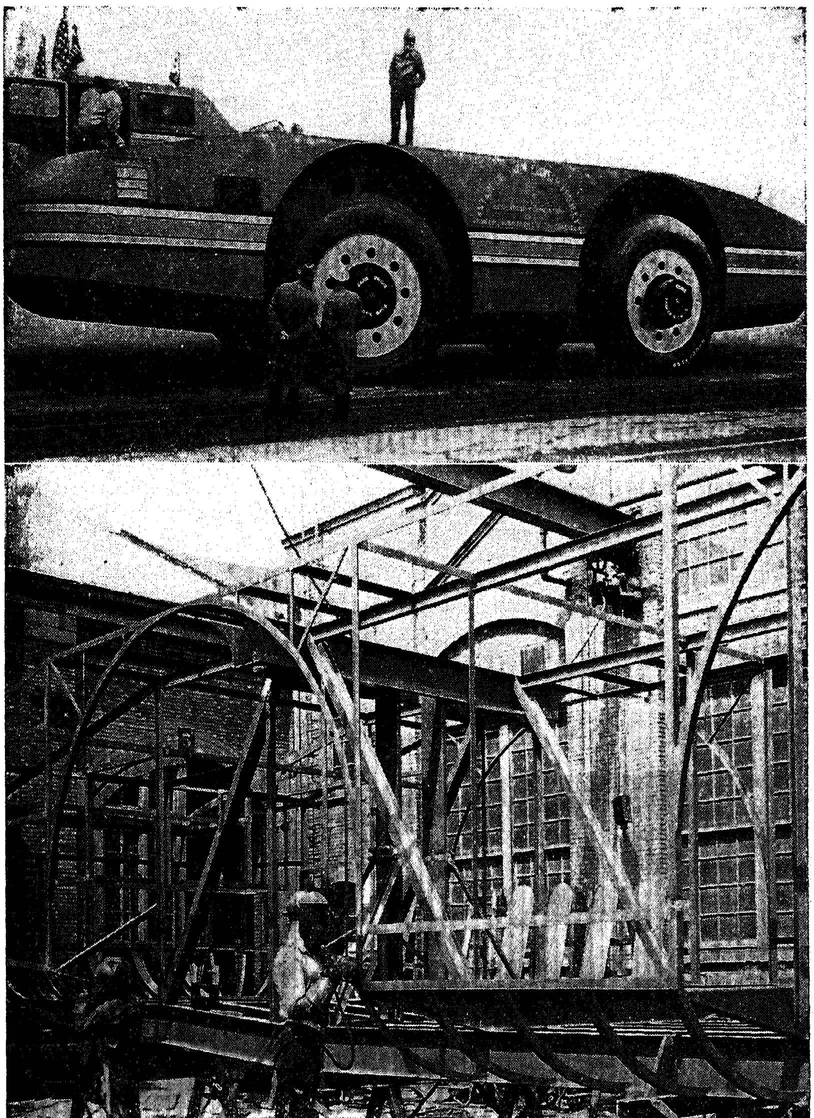


Fig. 1040. Antarctic "Snow Cruiser" to be used for exploration work at the south pole. Frame work includes 16,000 lbs. of high tensile steel. Welded construction saved 30% in weight, affording greater cruising range.

Fig. 1041. "Tucker Tank," anti-aircraft combat car of welded steel construction. Can climb 50% grades. Cruising range 225 miles. Top speed 114 miles per hour.

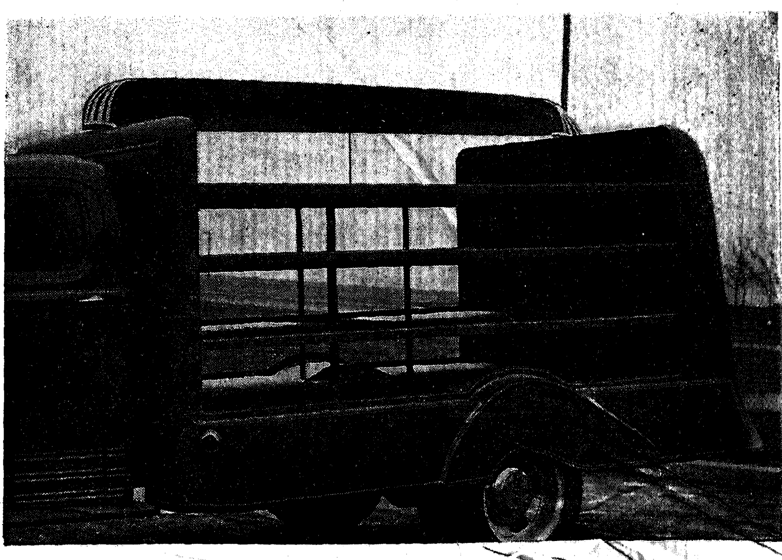


Fig. 1042. A welded steel body for a delivery truck. Changeover to this construction improved the appearance of the body, made it more rigid, cut weight and reduced construction costs materially.

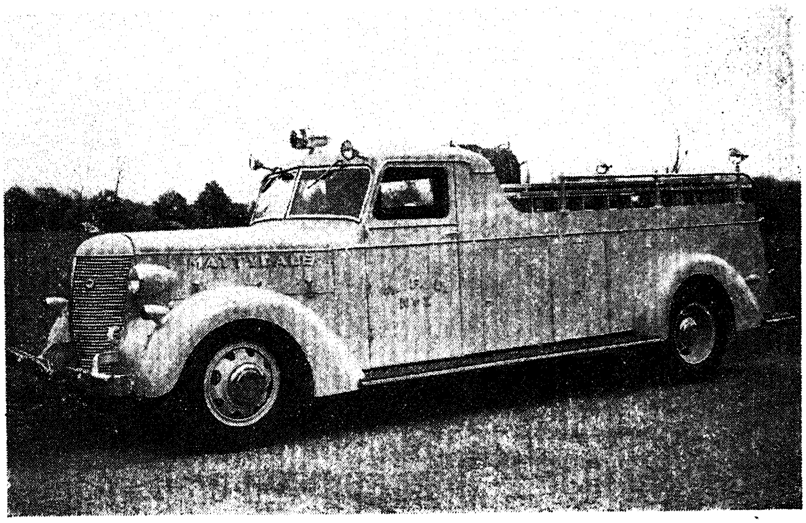


Fig. 1043. One of an order of 25 fire trucks with welded steel bodies delivered to a large eastern city.

Fig. 1044. Delivery truck with seamless tubular frame of welded construction. Tubing is 3-inches o. d., 12 gauge wall thickness.

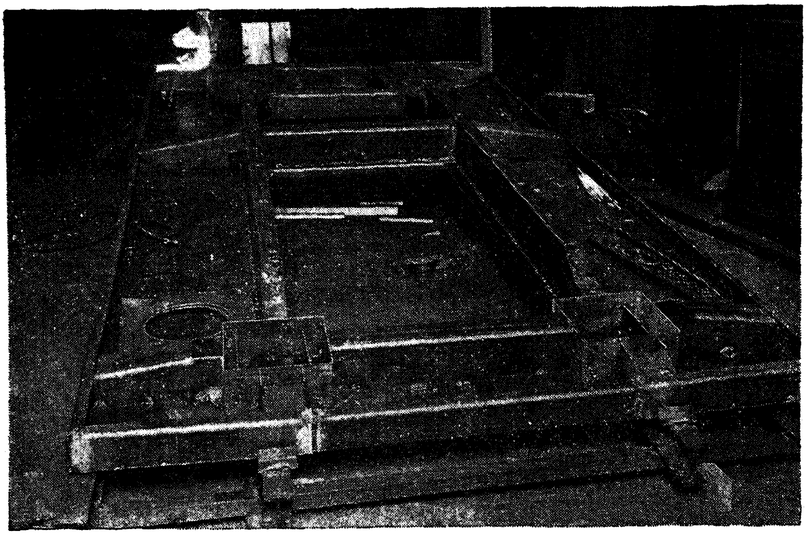


Fig. 1045. Truck frame, built from high tensile steel by arc welding. Weight savings 33⅓%.

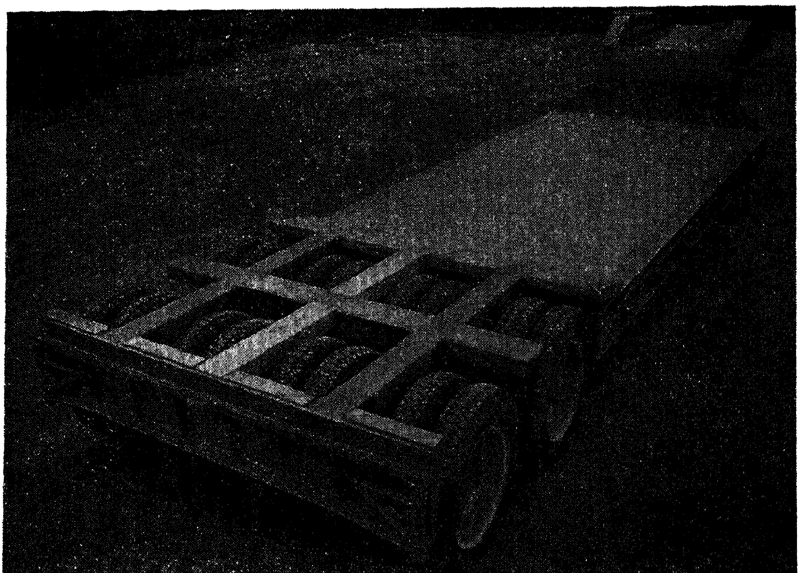


Fig. 1046. 30-ton welded trailer for hauling heavy construction machinery. Formerly of riveted construction. Welding reduced weight 750 lbs., cost 10%, construction time 10%. Increased strength and rigidity enabled the trailer to carry 15% heavier loads.

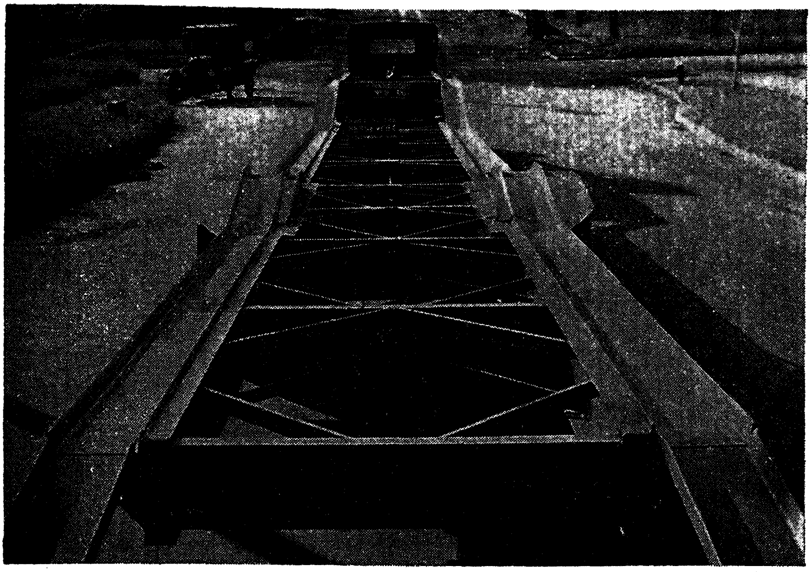


Fig. 1047. Arc welding is used extensively to build automobile carriers—both the type shown and the double deck type.

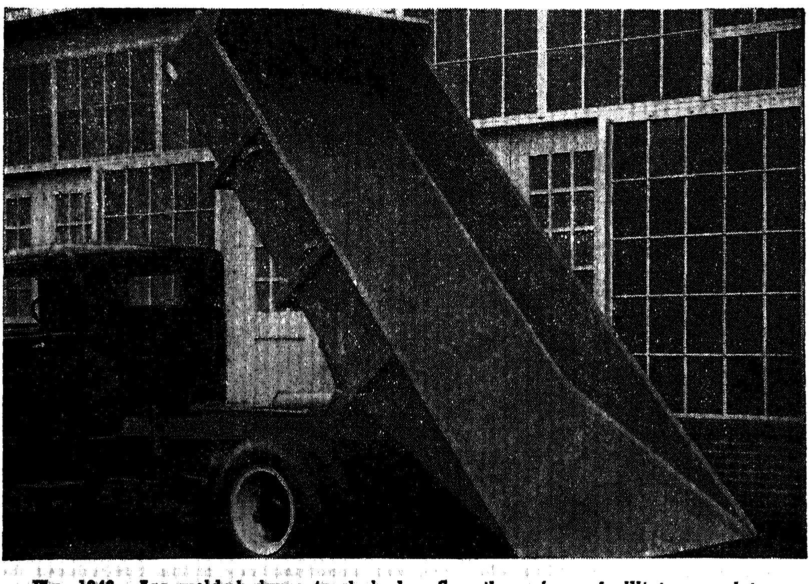


Fig. 1048. Arc welded dump truck body. Smooth surfaces facilitate complete unloading.

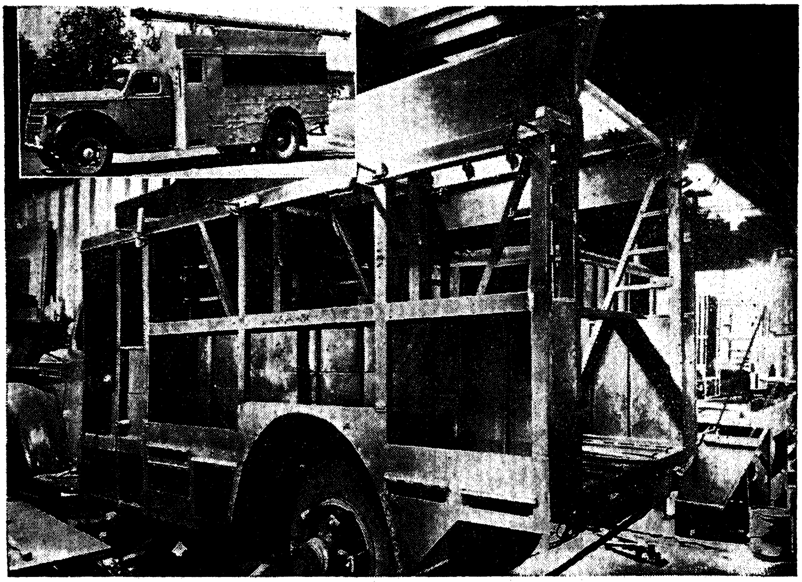


Fig. 1049. Service truck used by a Public Utility. Welded construction with high tensile steel saved 10% in weight over riveted construction, and reduced cost substantially.

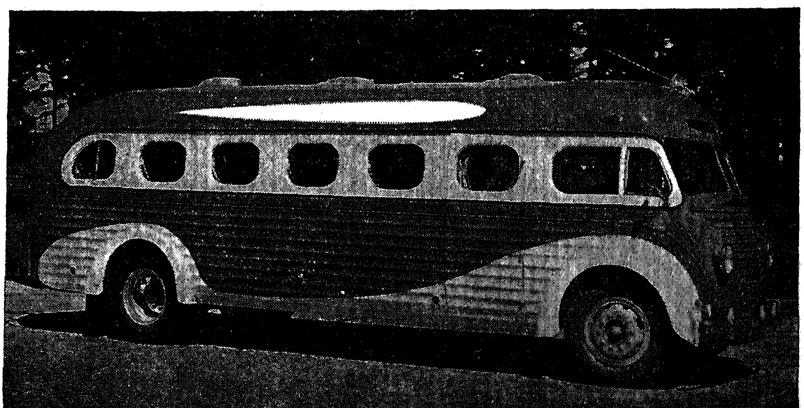


Fig. 1050. The arc welded alloy steel and aluminum body of this bus reduced the gross weight 2,000 lbs., resulting in savings of several hundred dollars annually in operating cost.

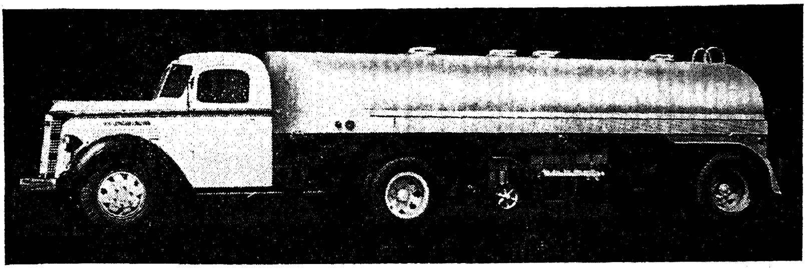


Fig. 1051. Trailerized tank of high tensile welded steel construction. This design provides an increased payload of 1100 lbs. as compared to conventional combination tank and trailer.

Fig. 1052. Repairing a cracked fender with carbon arc process and copper alloy filler rod. Center: Completed weld, 10-inches long, made in 5 minutes. Right: Finished fender after grinding, soldering, buffing and painting.

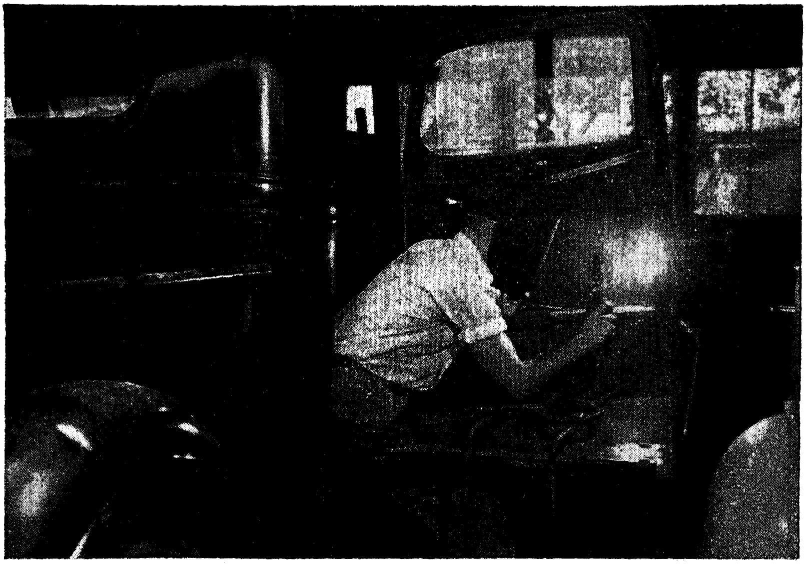


Fig. 1053. Installing a guide channel for glass in a damaged door. Simple tack welds do the job.

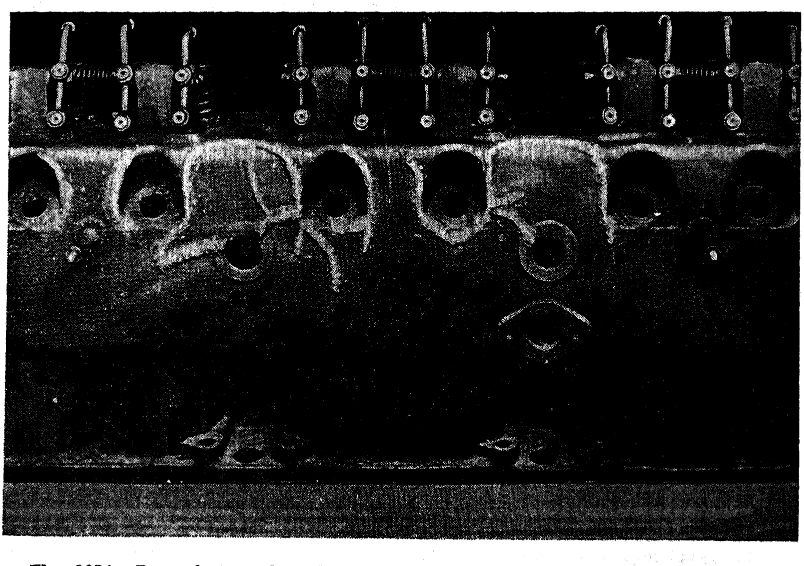


Fig. 1054. A cracked engine block repaired with shielded arc electrode using cast iron procedure given on Pages 326 to 333.

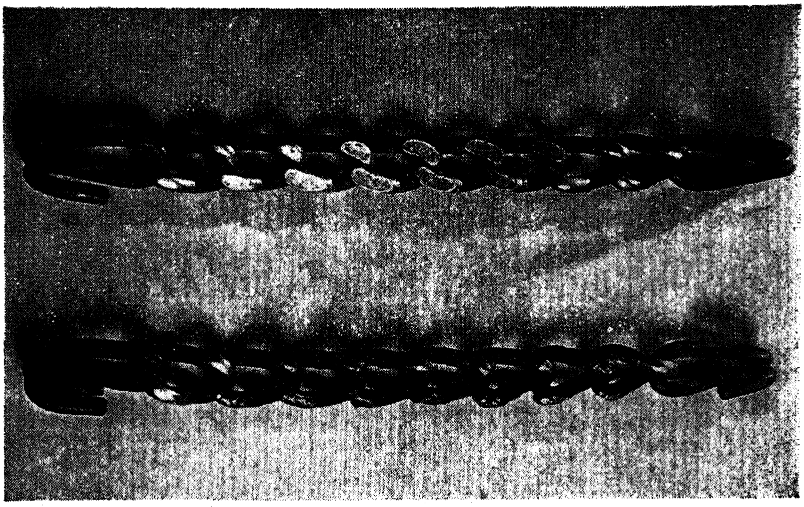


Fig. 1055. Truck chain cross links before and after reclamation with abrasion and impact resisting deposit. (Page 360). Cross links cost 35c and normally last less than a month. Hardfacing costs 6c each. Prolongs life to one or two seasons.

Fig. 1056. Building special base for front right seat of car to permit easy removal. Bar feet slip into holes in car floor.

Fig. 1057. Repairing cracked auto frame by welding splice bar over break in bottom flange of frame channel.

Fig. 1058. Welding on $4\frac{1}{2}$-inch pressed steel channels to $12\frac{1}{2}$-inch sides of truck, increasing capacity from $1\frac{1}{2}$-tons to 2 tons.

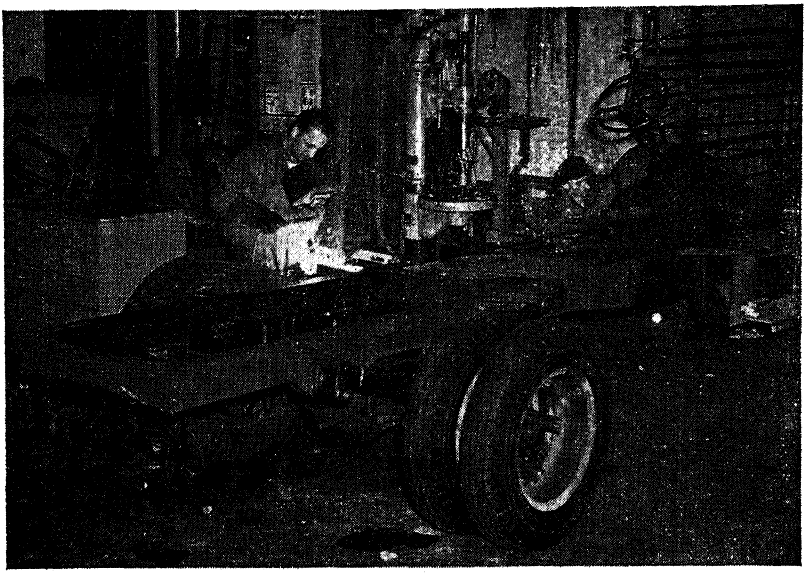


Fig. 1059. Fabricating 20-foot truck frame from 6-inch channel and salvaged parts of a fire-damaged truck. Total welding time 6 hours. Saved $75 over riveted construction.

Fig. 1060. Wrecker designed and built by a garage. Can handle up to 15-ton trucks. Boom telescopes out to 32 feet.

Barrels and Other Small Containers

Containers such as steel beer barrels and metal drums are generally welded automatically by the shielded carbon arc process. To withstand rough handling, the welds must possess high tensile strength and ductility as well as good corrosion resistance. Component parts of metal beer barrels are first pressed to shape and when fitted together provide circumferential seams for welding. A typical set-up for welding beer barrels is shown in Fig. 1061. The welding head remains stationary while the barrel is rotated under the arc.

Other containers produced by arc welding, both manually and automatically, are shown in Fig. 1062 and Fig. 1063 and in other sections of this chapter. For example, see Figs. 1121 to 1123 under Machine Parts.

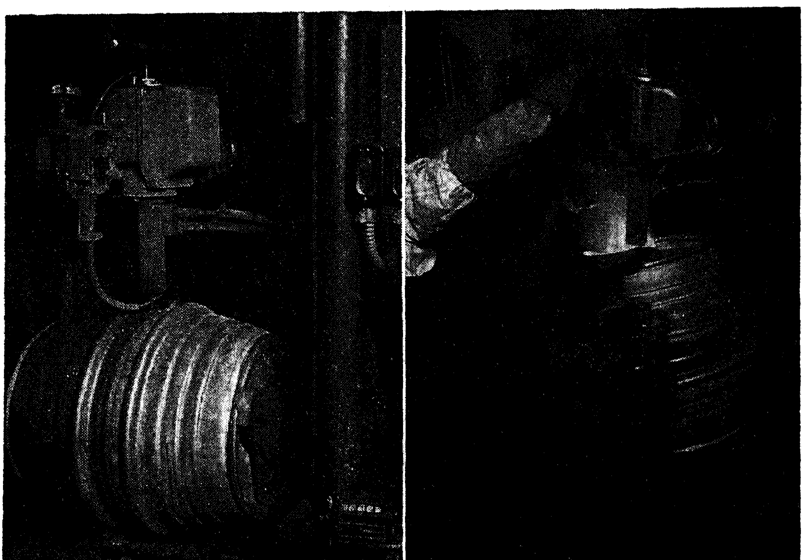


Fig. 1061. Left: Set-up for making the girth weld of a beer barrel by the automatic carbon arc process. Right: Welding the ends of beer barrels by the automatic carbon arc process.

Fig. 1062. Welding three and five gallon capacity fuel tanks for portable kerosene burners.

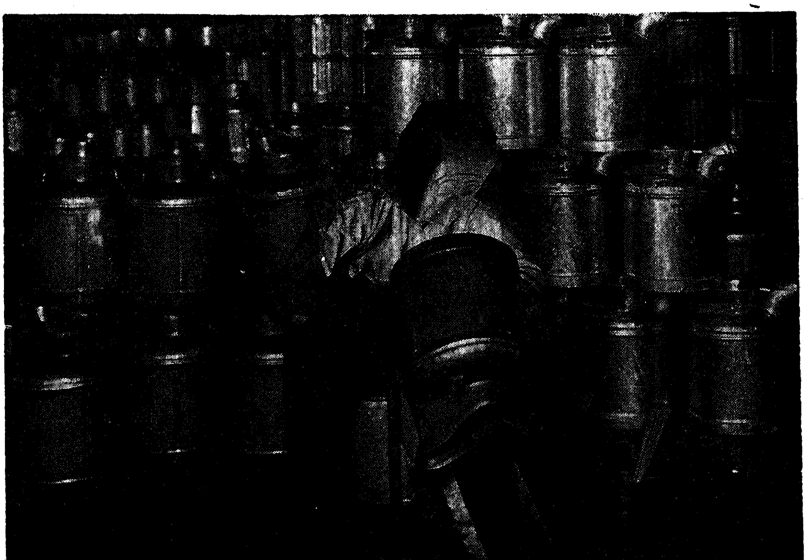


Fig. 1063. Welding gasoline cans of 18-gauge and 20-gauge steel.

Bridges and Piers

A large number of bridges—both highway and railroad—have been built by electric arc welding. This includes a wide variety of types and sizes. Typical ones are illustrated in the following illustrations. Arc welding is also used extensively in the maintenance and strengthening of existing bridges, affording a simplified means of adding new steel plate or replacing worn out flooring, etc., for greater safety and economy. A number of applications along this line are shown in Fig. 1064 to Fig. 1085.

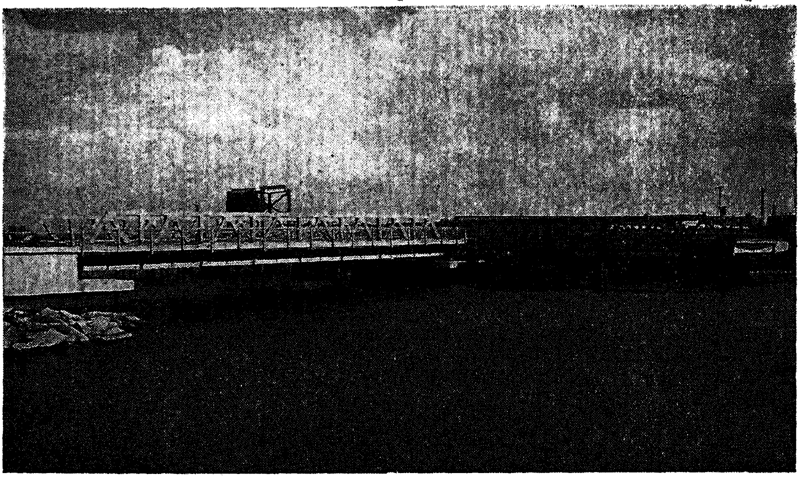


Fig. 1064. Completely arc welded highway bridge consisting of two approach spans 192 feet long and a 160-foot center swing span.

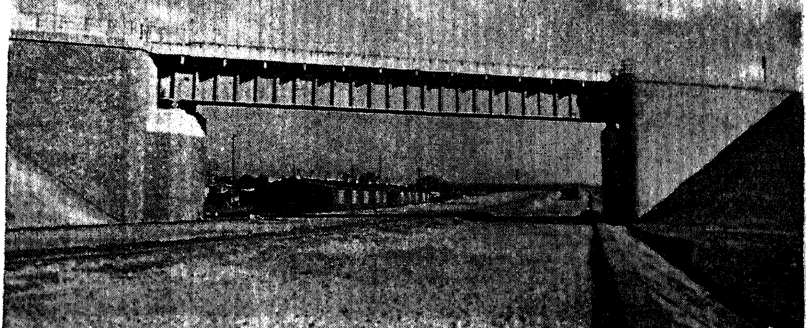


Fig. 1065. Plate girder type railroad bridge—one of more than two hundred all welded structures erected in Germany.

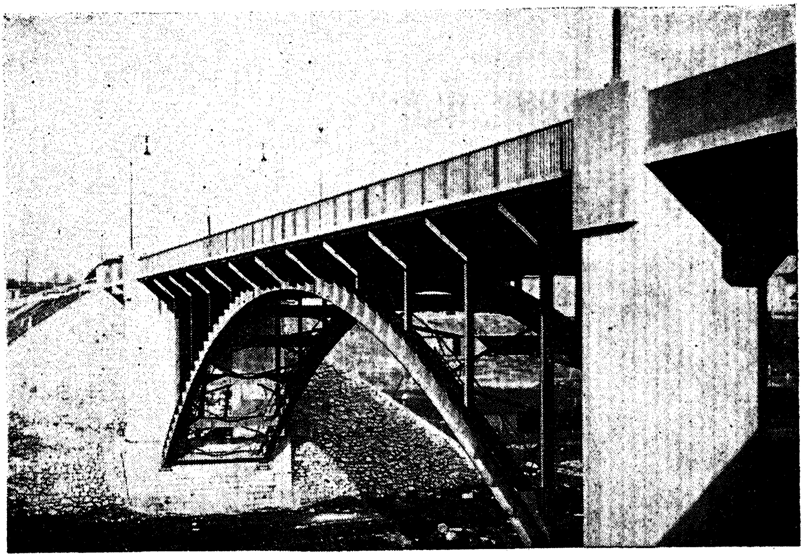


Fig. 1066. Two-hinged arch highway bridge, 166 foot span, all welded construction, located in Bohemia.

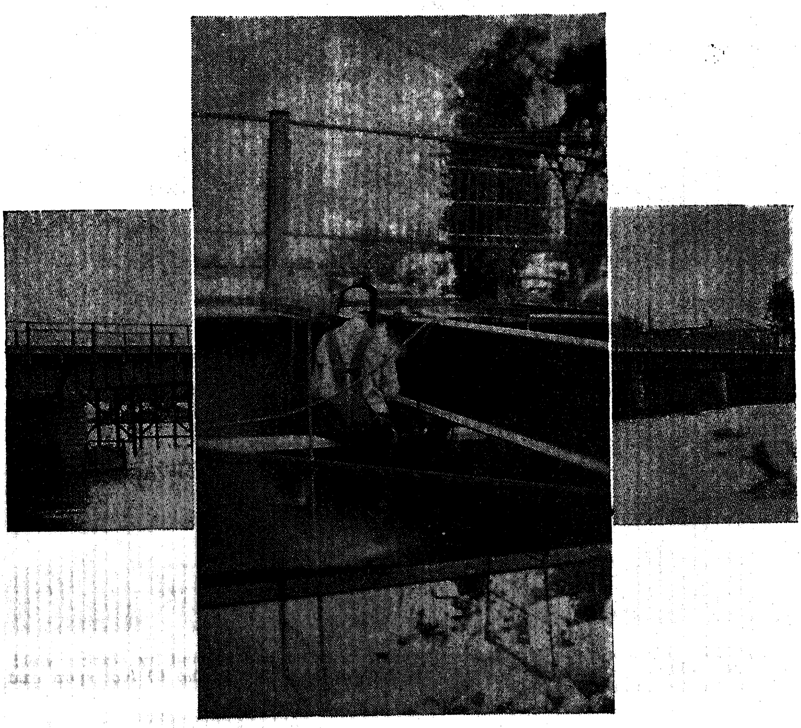


Fig. 1067. Largest welded bridge built in Canada—a highway bridge across the Ste. Anne River. Inset shows operator welding floor beam to stringer.

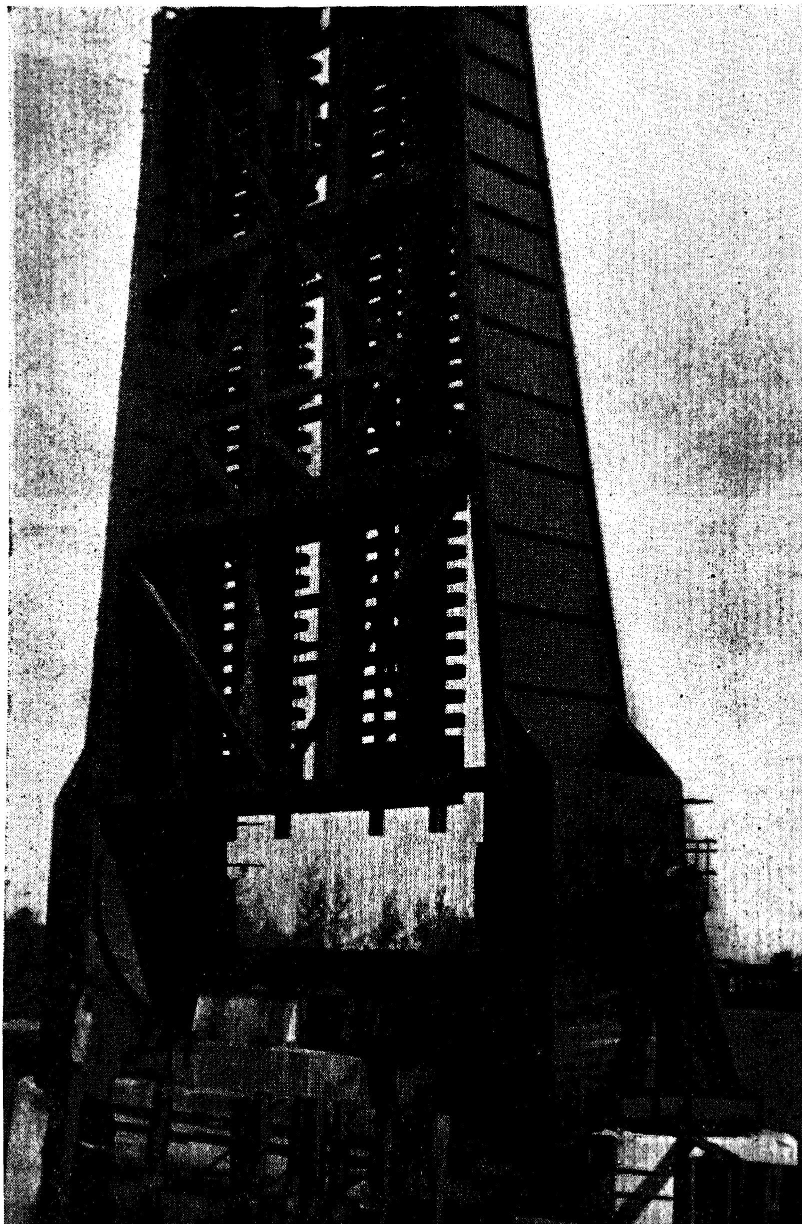


Fig. 1068. Bascule span of railway bridge fabricated and erected by electric welding. Arc welding permitted a weight reduction of 42½ tons in the 60 foot span and 100 tons in the counterweights.

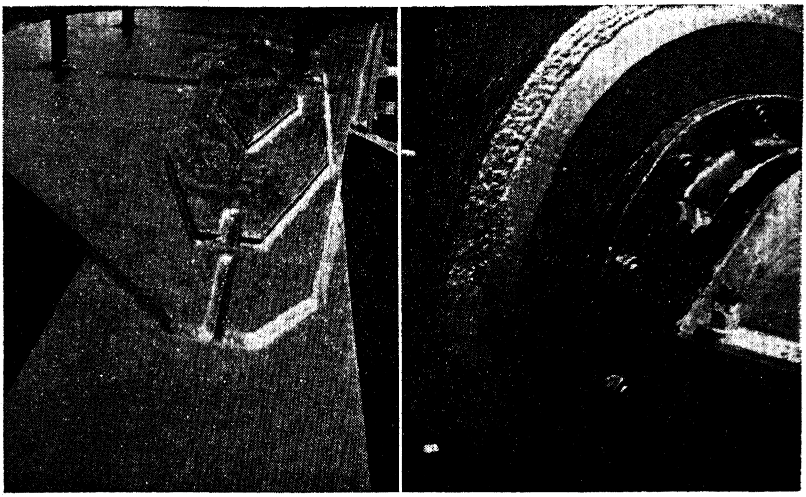


Fig. 1069. Details of bascule bridge shown in Fig. 1068. Left: Arc welded connection of main girders to bottom counterweight section. Right: Close-up view of arc welded trunnion connection to counterweight box showing beveling of plates and fillet weld.

Fig. 1070. Bridge flooring of $\frac{5}{8}''$ structural silicon steel plates being placed by arc welding in construction of the Tri-Borough bridge in New York.

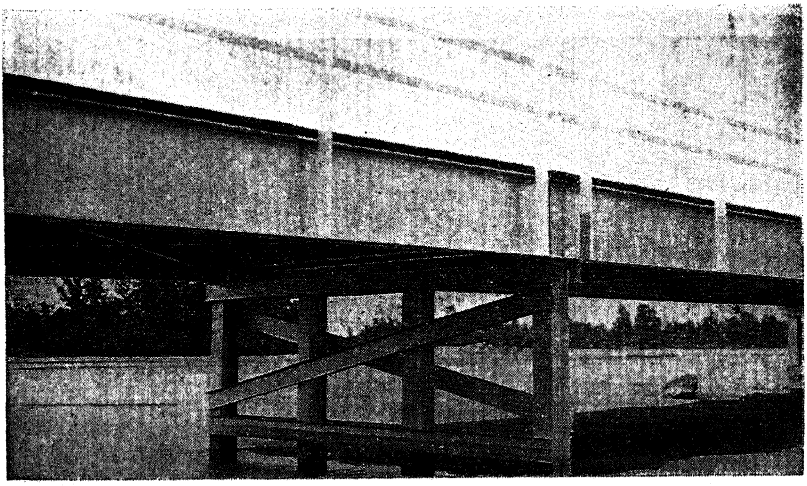


Fig. 1071. Closeup of all-field-welded bridge showing open steel piers, caps, bracing and hand rails. Typical of many secondary road all-welded bridges totaling more than 1000 tons of steel built in the middle west. See also Fig. 1072.

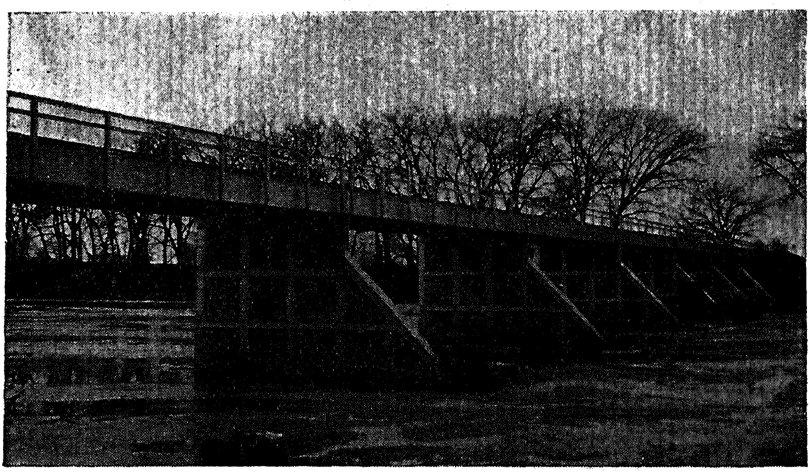


Fig. 1072. Secondary road bridge of all welded construction. Steel pile piers and ice breakers have concrete webs above water line to prevent lodging of trash. All fabrication in the field by welding for simplicity and economy.

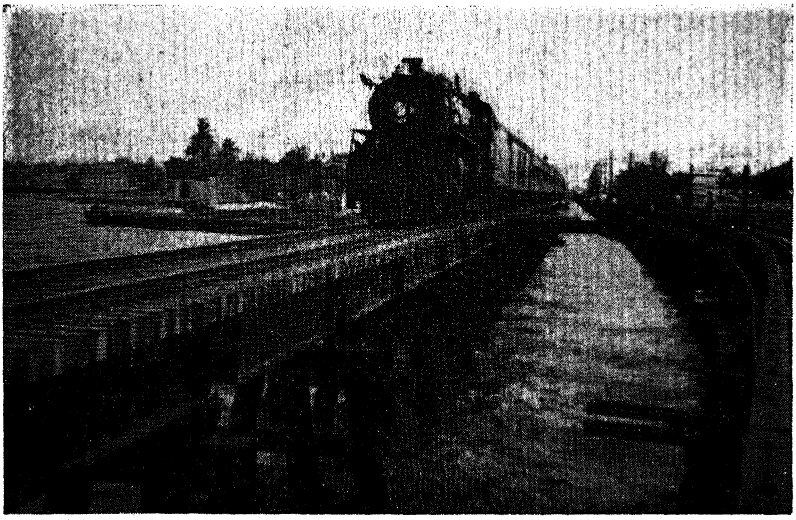


Fig. 1073. All welded steel railway trestle for main line use fabricated at the erection site in Florida. 1200 ft. long. Girders 36" x 160 lbs. with cross frames carried on four-pile bents spaced 23' 6" to 30'. Estimated savings 33% over conventional construction costs.

Fig. 1074. Widening of highways often does away with existing bridges which may be salvaged and re-erected for secondary roads. This skew-end bridge is an example. It was formerly a pin-connected high truss type bridge with square ends. New portal struts and knee braces were installed by arc welding to provide additional rigidity.

Fig. 1075. Tall trucks occasionally hit the braces of old bridges such as this. The braces are being replaced with welded-on gusset plates such as shown at the left. This adds 7½ feet more clearance. One of the old braces is shown on the right-hand side of the illustration at the left.

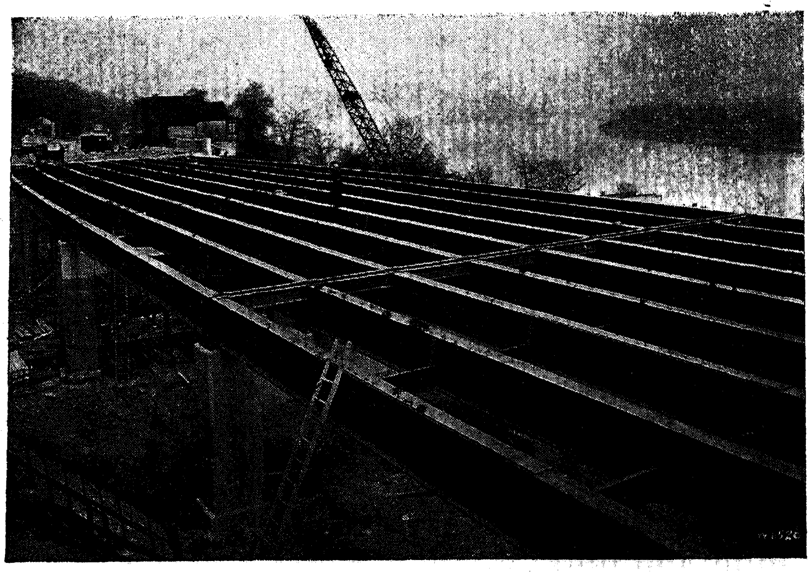


Fig. 1076. Highway viaduct of welded steel construction. 297 feet long, 70 feet wide. 305 tons of rolled shapes, including 36" x 12" x 194 lb. I-beams for stringers.

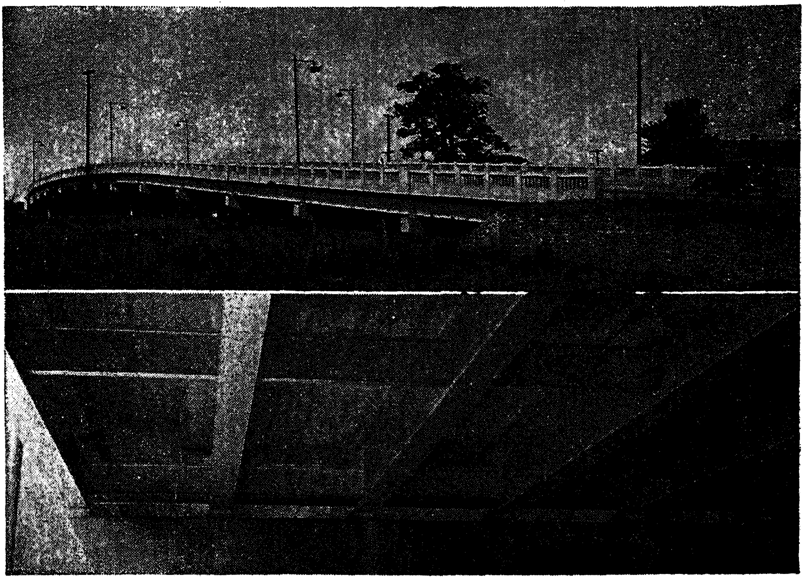


Fig. 1077. Over pass of welded steel construction. Length 900 ft. Consists of 24" I-beam stringers with three cross beams per span as shown at bottom.

Fig. 1078. One of two 122-ft. all welded over-pass spans for Main Avenue bridge, Cleveland, Ohio. One girder is shown in place and welders are working on the double V groove web joint.

Fig. 1079. Joining girder frame to column on one of the spans shown in Fig. 1078. Shop fabricated frame includes a 38 ft. length of 36" x 300 lbs. girder and plate welded into the interesting design shown. Column is 14" x 211 lbs.

Fig. 1080. Welding one of the single groove flange joints in the girder of Fig. 1078. Flange is 1.71" thick and 16" wide. Note also the joint in the bottom flange and in the web.

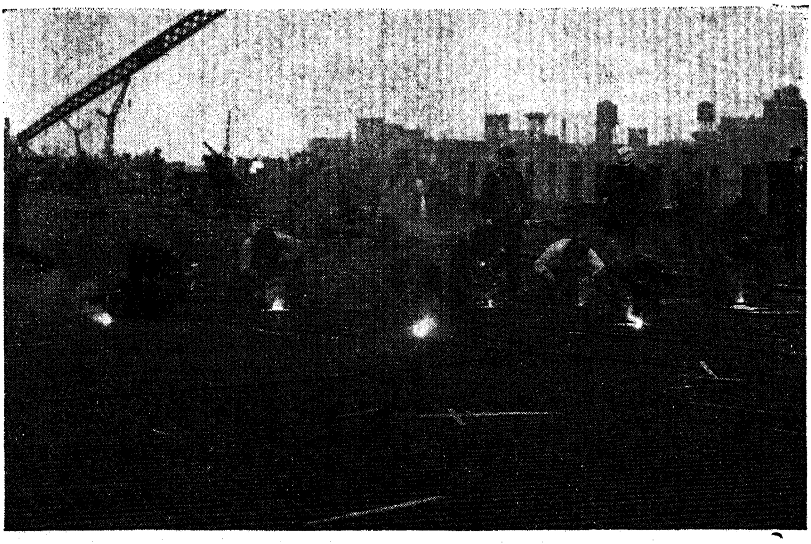


Fig. 1081. Joining sections of steel grating in the Main Avenue bridge, Cleveland, Ohio. This type of flooring was used exclusively for this mile-long bridge. Welding on the bridge, including railing, flooring and structural members, totalled 70 miles of joints.

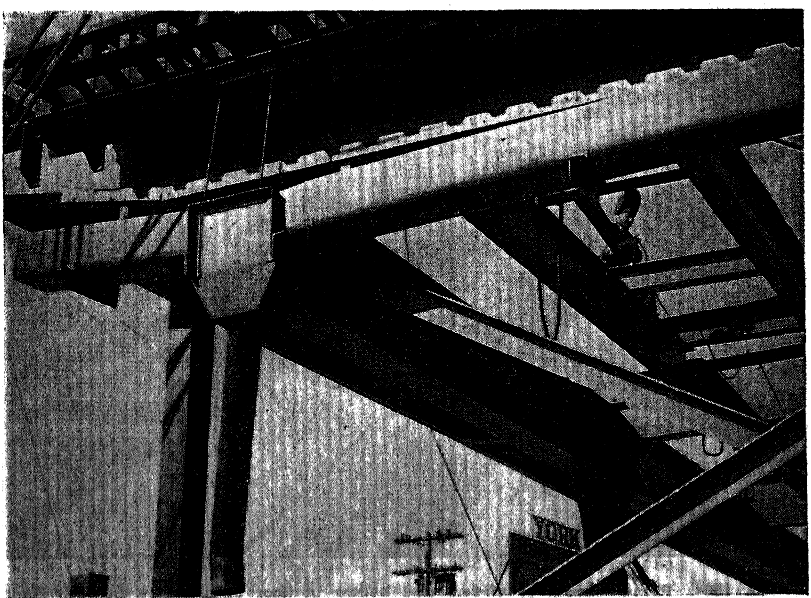


Fig. 1082. View of an end of the welded steel span of Fig. 1078 showing welded steel drainage spouts. Note also welded girder frame and floor beam construction.

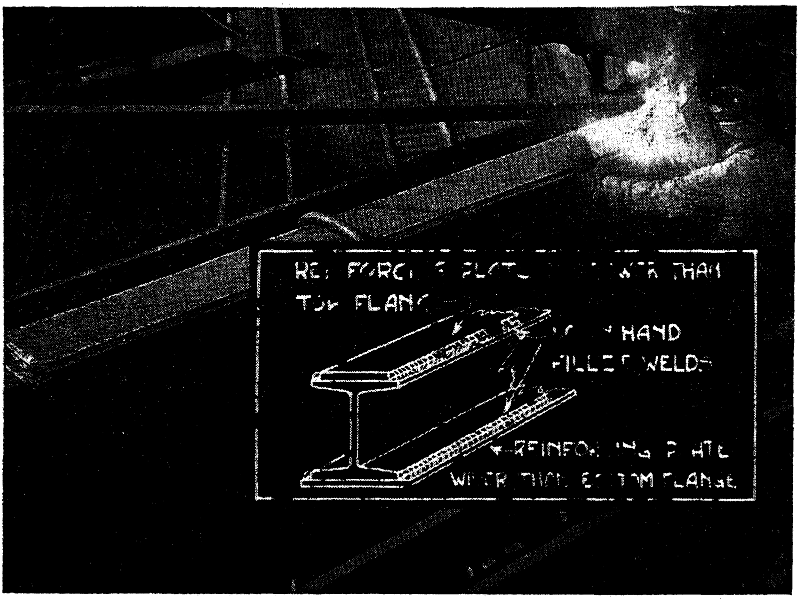


Fig. 1083. Top and bottom flanges of floor beams in highway bridge reinforced by welding on new steel plate as shown.

Fig. 1084. Reinforcement of girders and beams in floor of highway bridge. New steel plate is welded to top and bottom flanges of beams. I-beams with webs cut as shown are welded to stringers. Total welding 26,000 ft., including welding on new steel grating.

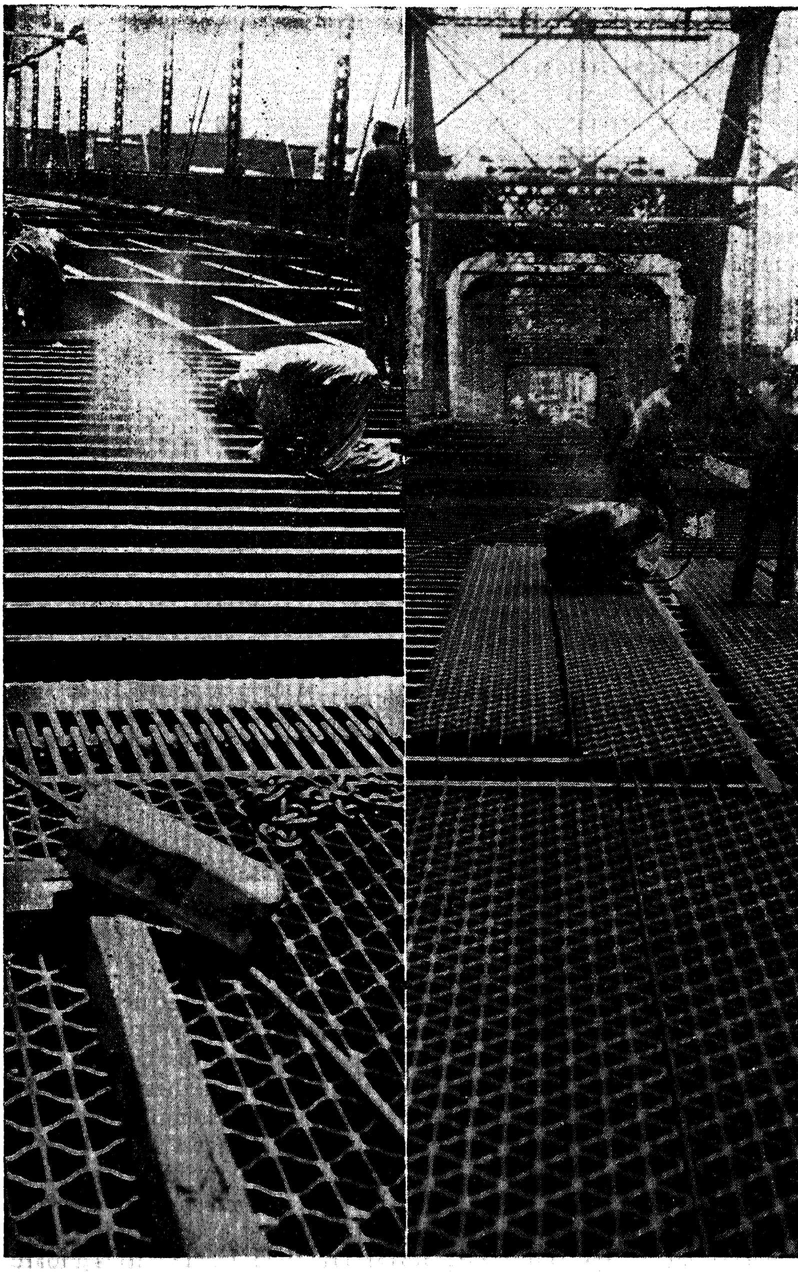


Fig. 1085. New steel cross beams (left) and grid type flooring applied to highway bridge in Penn. for length of 1119 ft. and width of 29 ft. 6 in. New steel floor weighs half as much as old wooden floor, enabling increased live load from H-15 to H-20 loading. Construction time one-half that required for wood floor. New steel-concrete floor is skid proof.

Buildings and Houses

The structural framework of hundreds . . . even thousands . . . of buildings has been fabricated and erected by arc welding, providing maximum strength, rigidity and economies through savings in time and steel tonnage. These structures include office buildings, mill buildings, warehouses, hangars, houses and many other types ranging in heights from one story to seventeen stories. A few of these typical buildings are shown in Figs. 1086 to 1102. For welded design information on structural steel see Pages 521 to 757.

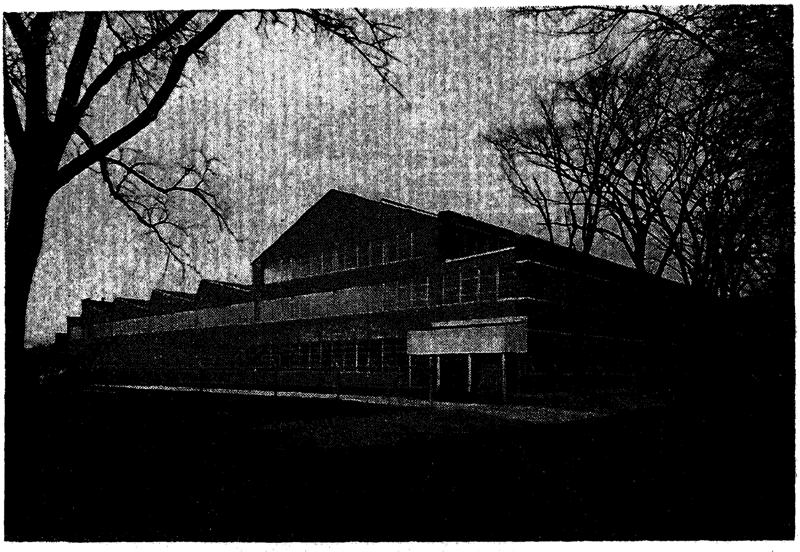


Fig. 1086. All welded steel building of rigid frame construction. Contains 200,000 sq. ft. of floor space.

One of the most interesting developments in the structural field brought about by welding is that of rigid frame construction discussed on Pages 652 to 718. Several examples of this modern construction are shown on the following pages. One of these, shown in Fig. 1086, is a two-story industrial building containing 200,000 sq. ft. of floor space. Shop fabrication and erection views are shown in subsequent illustrations. The "tree form" sections are fabricated from plate which has been cut and rolled to proper size and shape, and placed in jigs for welding. A typical fabricating operation is shown in Fig. 1089. These fabricated forms are then welded to standard rolled shapes in the shop, thus providing the main columns and stud columns of the building. The 65-ft. rafters of the larger section of this building were shipped to the job in two parts. The two parts, including a shop fabricated beam section and a standard I-beam sec-

tion, were joined at the erection site and the assembly was then lifted into place as shown in Fig. 1090. In like manner, the rafters of the "tree form" were prefabricated and erected with a minimum amount of field welding.

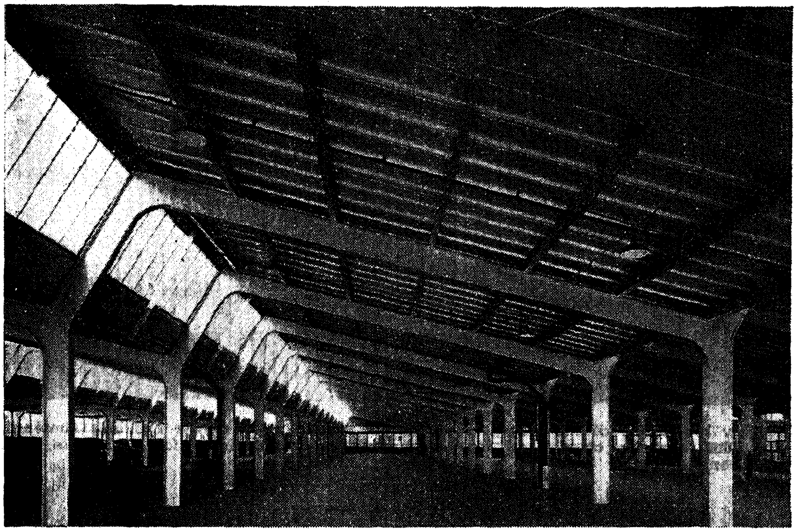


Fig. 1087. View of one bay in the saw tooth section of the second floor of the building shown in Fig. 1086. Note improved lighting and head room through elimination of trusses.

In the construction of the building, involving 1314 tons of steel, 29,600 linear feet of welding were used. Of this amount, 25,000 linear feet were shop welded.

This particular building well illustrates the progress that has been made in the construction of welded buildings in the past five years Fabricating shops are now set up to produce welded structural members with maximum speed, economy and accuracy. This 1314 ton structure was built in only four weeks' time. In one eight-hour day, 93 tons of steel were erected. It is estimated that fabrication costs and erection costs were both 10% less than for conventional construction.

The detail connection shown in Fig. 910 illustrates how the floor beams are rigidly connected to the columns so as to provide the rigid frame construction of the building.

The two views shown in Figs. 1087 and 1088 illustrate the benefits of this beam type construction. Absence of trusses gives greater head room between floor and roof for production equipment. Better illumination is also secured.

Detailed connections in this structure of rigid frame design are shown in Figs. 907 to 910.

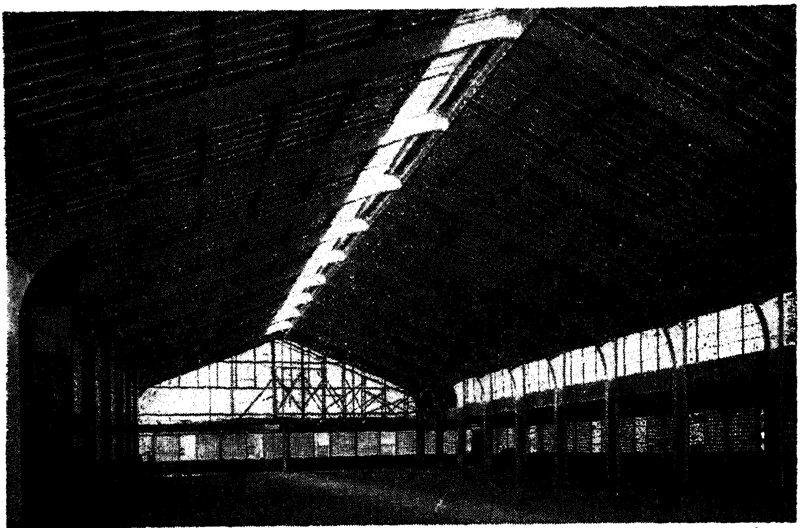


Fig. 1088. One of the larger rooms in the second story of the building shown in Fig. 1086, showing clear head room between floor and ceiling afforded by the beam type construction.

Fig. 1089. Fabricating a "tree form" stud column for one of the connections such as shown in Fig. 1087.

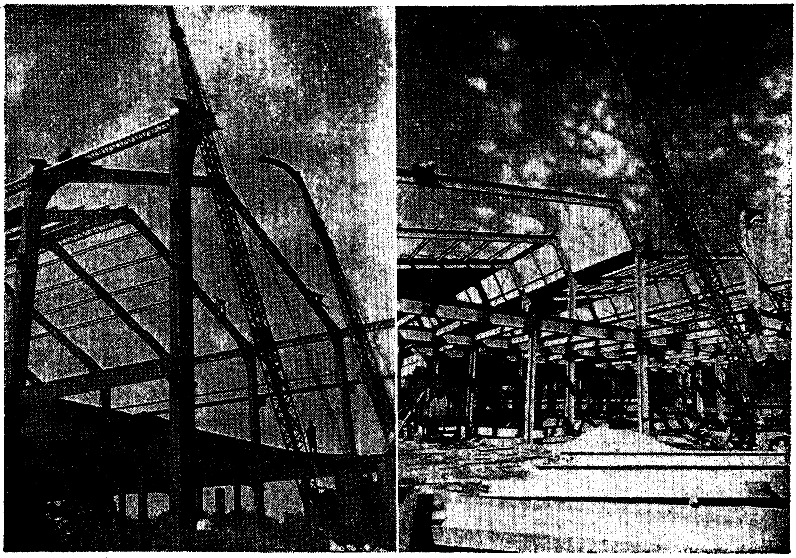


Fig. 1090. Left: Construction view showing the erection of a 65-ft. rafter beam. Right: Erecting the beam of one of the saw tooth sections.

Fig. 1091. All welded steel office building at Frankfort, Ky. Construction view shows nine of the fourteen stories erected. Total tonnage 1470. Estimated savings in weight 10% through welded design.

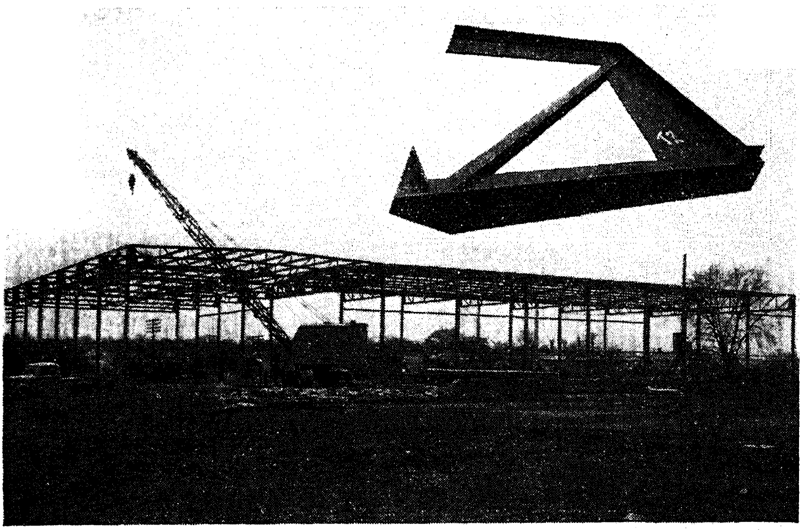


Fig. 1092. A one-story welded mill building 126 ft. long, 50 ft. wide, in "L" shape. All steel fabricated at erection site. Top and bottom cords for struts made by splitting a wide flange beam. Web system consists of angles welded to small T's, eliminating gusset plates. (See inset.) Weight saving over riveted construction 20%. Only equipment required for complete fabrication and erection was punch, shear, cutting torch and arc welding equipment.

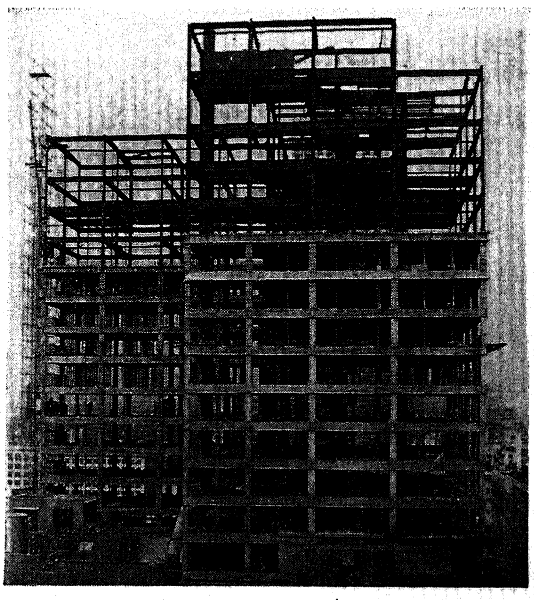


Fig. 1093. Thirteen-story addition to Chamber of Commerce Building, Houston, Texas. Fifteen tons of steel. Shop riveted. Field welded for noiseless construction. Includes 8,000 ft. of welded joints.

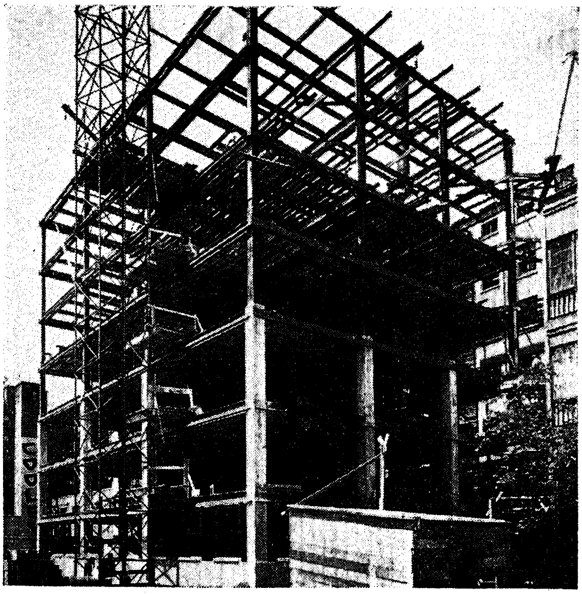


Fig. 1094. Tier type, all welded 7-story office building in Evanston, Ill. 35,000 sq. ft. floor space. 355 tons of steel. 4375 ft. shop welds. 1750 ft. field welds. Welding saved 25% in fabrication costs, 10% in erection costs, 10% in construction time.

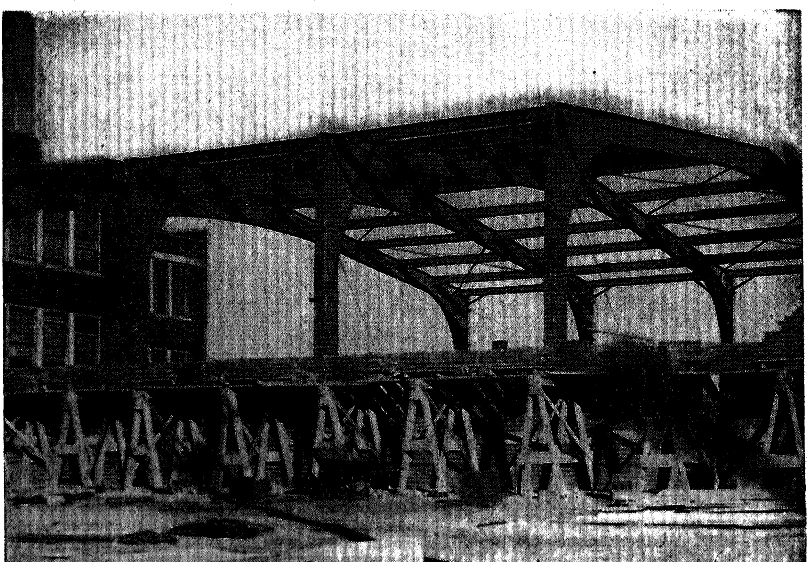


Fig. 1095. Rigid frame structure for rural high school in Kansas. Columns are 18 in. 50 lb. I beams. Rafter sections are 21-in. 59 lb. beams. Each of four frames weighs approximately 10,000 lbs.

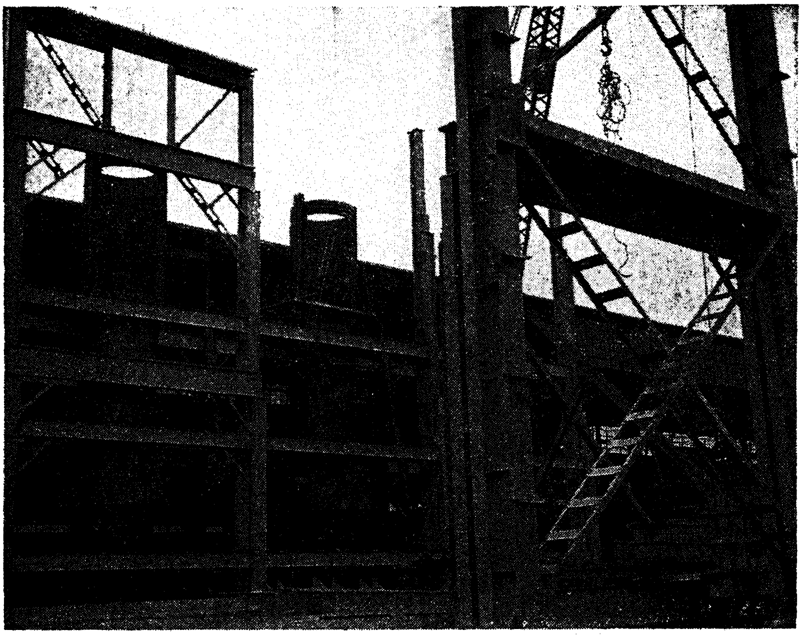


Fig. 1096. Welded steel columns for new foundry building fabricated from two 18 in. I beams, one 18 in. channel and four channel spaces with stiffeners. Height 70 ft. Will support two cranes at 30 ft. and 60 ft. levels.

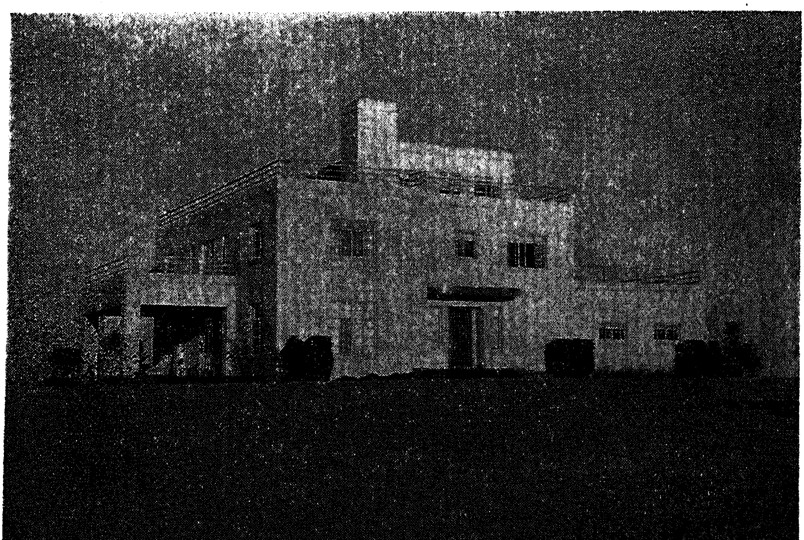


Fig. 1097. Welded framework for this 12-room home in Wichita Falls, Texas. Includes 96,000 lbs. of steel. Floor beams, 10 in. high, were shop fabricated from 2" x 2" x 1/4" angle and 1½" x 1½" x 3/16" lattice. Maximum beam span is 18 ft. Walls have 3 in. channel studs with ¾" lath channel and expanded metal lath. Welded steel framework added 15% to the cost of the house frame but reduced insurance rates from $1.50 per hundred to 30c per hundred.

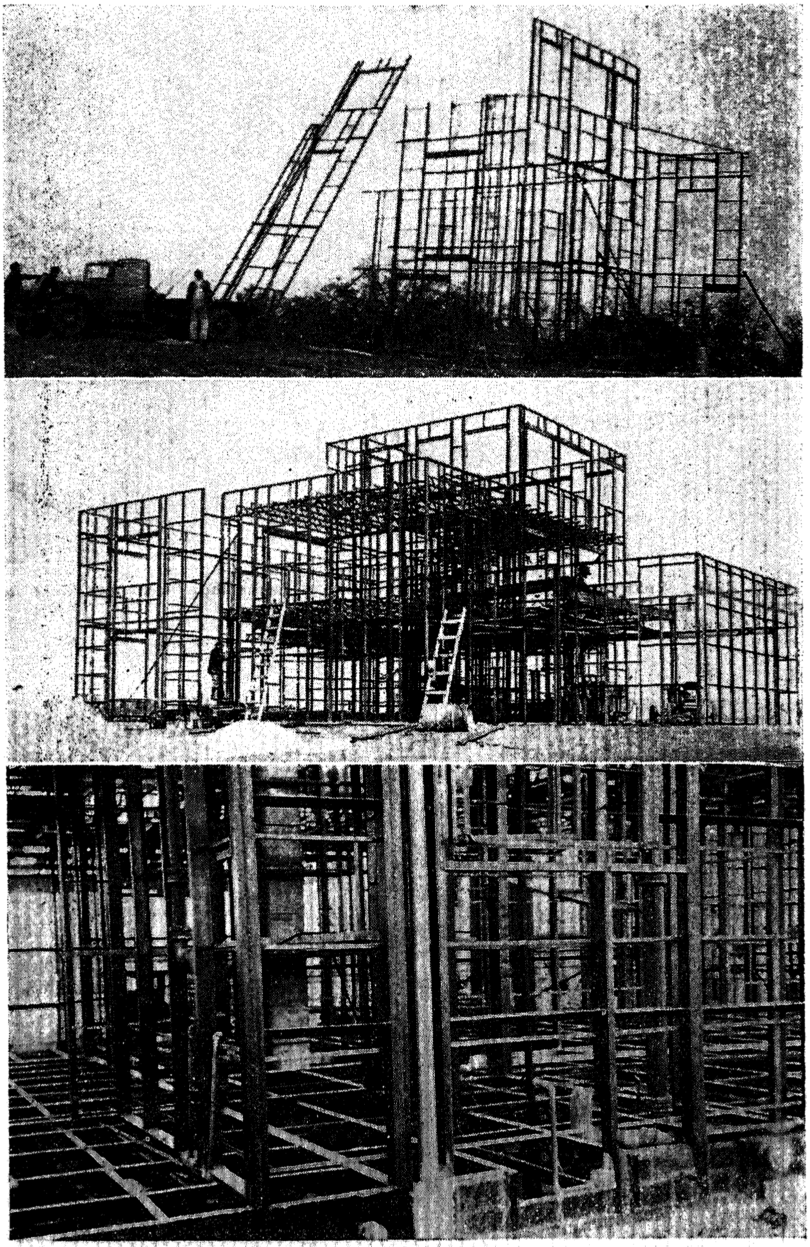


Fig. 1098. Erection view, completed structure and close-up of portion of 12-room house shown in Fig. 1097. Floor beams, 10 in. high, were shop fabricated from 2" x 2" x 1/4" angle and 1½" x 1½" x 3/16" lattice. Maximum beam span is 18 ft. Walls have 3 in. channel studs with ¾" lath channel and expanded metal lath.

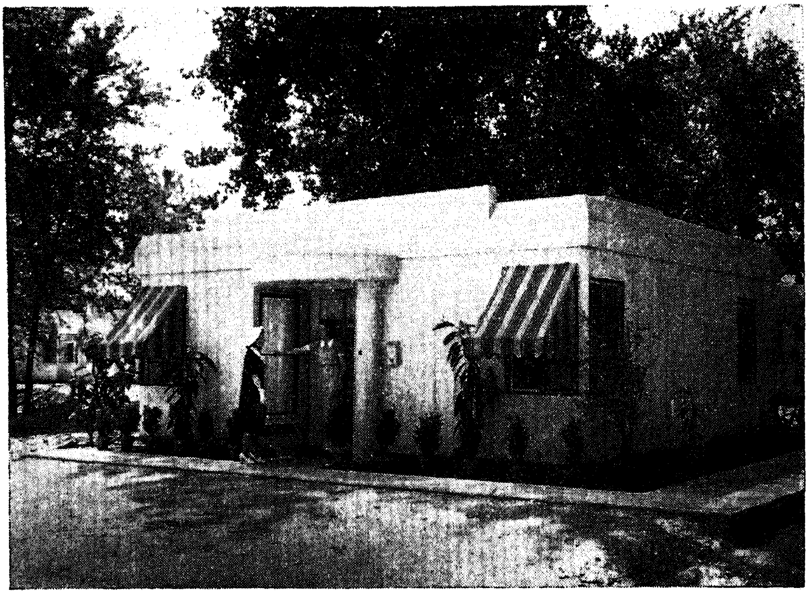


Fig. 1099. Welded steel 5-room residence — one of scores that have been built in Peoria, Ill. See Fig. 1100.

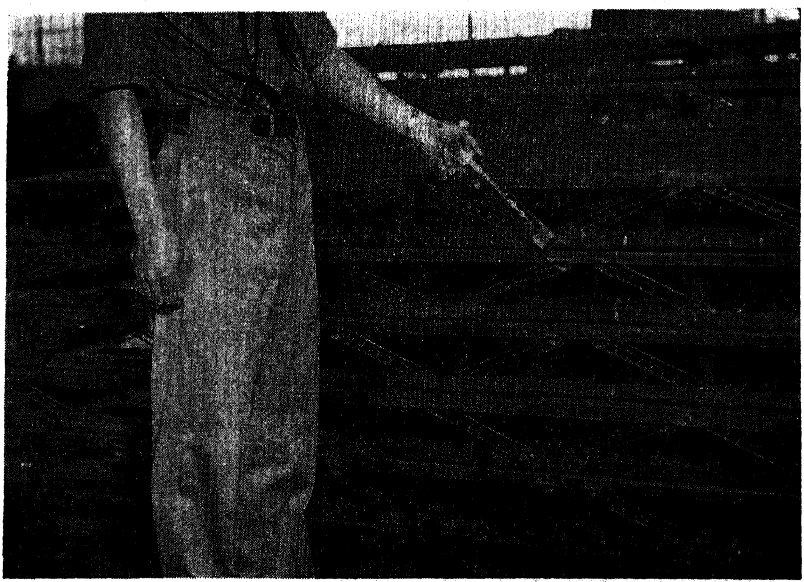


Fig. 1100. End view of wall panels used in the house shown in Fig. 1099. Two pressed steel panels are spaced apart by bars as shown. These sections are then blown full of mineral wool for insulation. Panels are completely wired with conduit and piping for electrical and plumbing connections.

Fig. 1101. House of 30,000 cu. ft. content with welded steel frame. Contains 10 tons of steel costing $190.00 per ton, erected and painted, including overhead. Extra cost over wooden frame is less than 10% of cost of building. Advantages: Eliminates plaster cracks. Rot and vermin-proof construction. Simplifies installation of heating, plumbing and electric equipment. Minimizes field work for quicker construction. Minimizes depreciation and insurance.

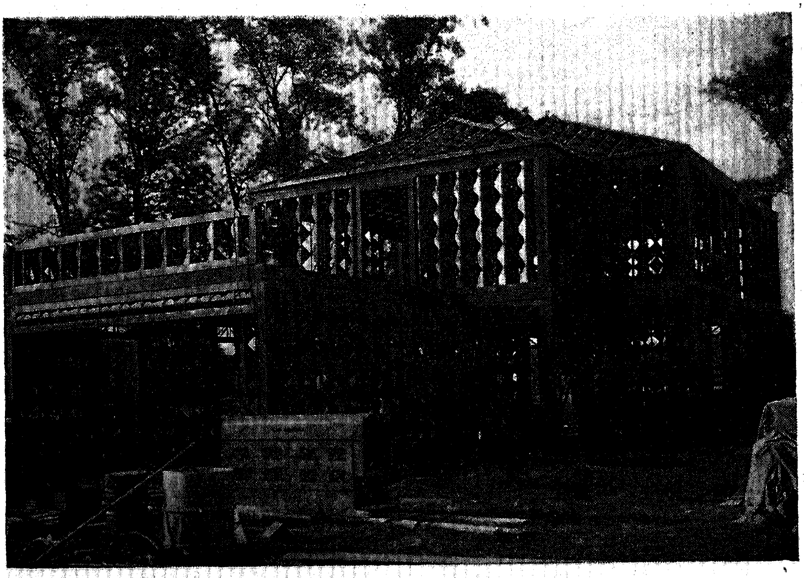


Fig. 1102. This all-steel arc welded home features a cellular construction. Panels for floor, walls and roof came to the job in sections completely fabricated and ready for assembly. The exterior of the house can be brick, stucco, wood or other material.

Fig. 1103. Substructure for rubber-cushioned press-room floor in Chicago welded to existing structure. Left: Connection of cross beams to 20" main columns through 18" channel section. Right: Connection of 30" I beam to main 30" girders.

Fig. 1104. Remodeling an office building. Arc welding permits the addition of stays to existing columns with a minimum of work and expense. Insert shows seat welded to column for support of floor beams.

Construction Equipment

The strength, rigidity and light weight of welded steel has played a prominent part in the progress of the construction industry during the past ten years, by affording machines and implements whose serviceability and performance far excel those of former designs. Welding has made it practical to build equipment (such as scrapers) which has revolutionized each-moving and construction practices for lower costs.

A few of these modern cost-saving machines are illustrated on the following pages.

Arc welding also saves money for the user of construction equipment by affording a means of repair and reclamation for broken and worn parts, minimizing valuable outage time of equipment and avoiding expensive replacements. A few typical applications are shown.

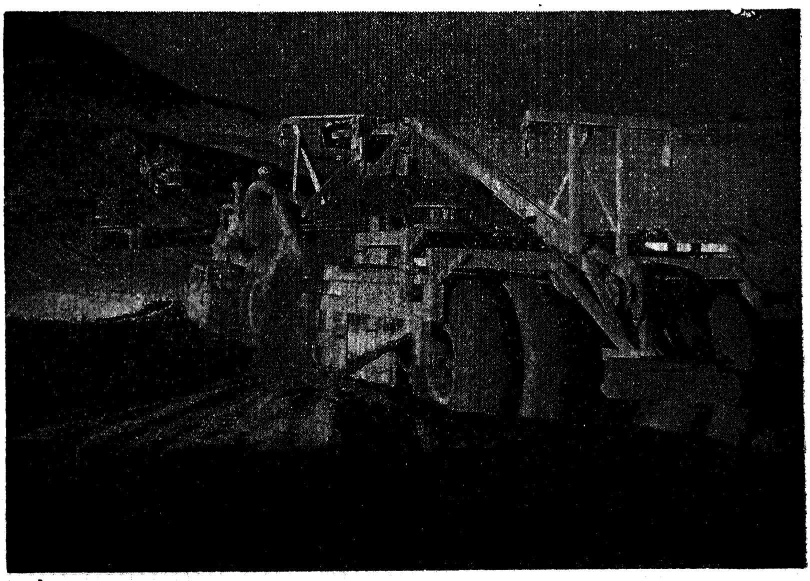


Fig. 1105. Welded steel "Carryall" scraper in operation.

Fig. 1106. Assembly line view of a scraper such as shown in Fig. 1105. Box beam construction is used extensively.

Fig. 1107. Welded steel "rooter" rips up shale, rock, boulders, concrete pavement and other hard surfaces.

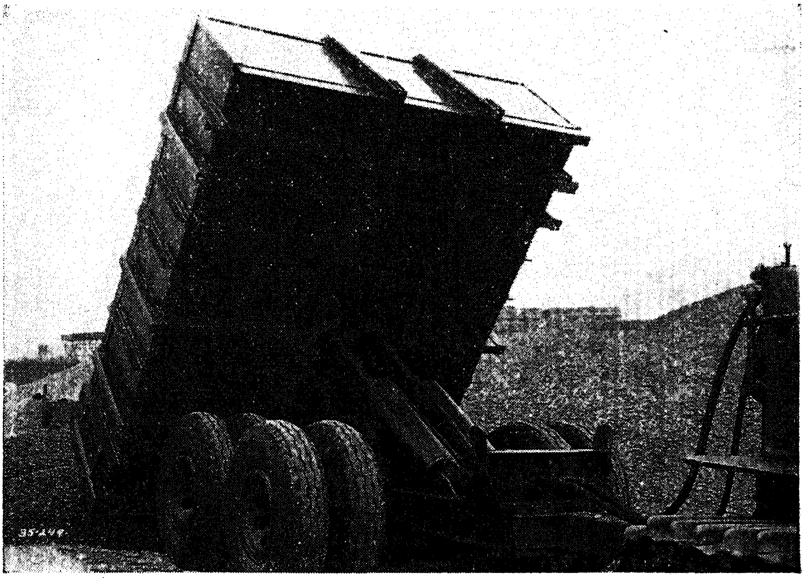


Fig. 1108. End dump "Karry Buggy" of all welded steel construction. Full load capacity 30 yards. Smooth interior facilitates unloading. Welded design increases pay load and minimizes maintenance.

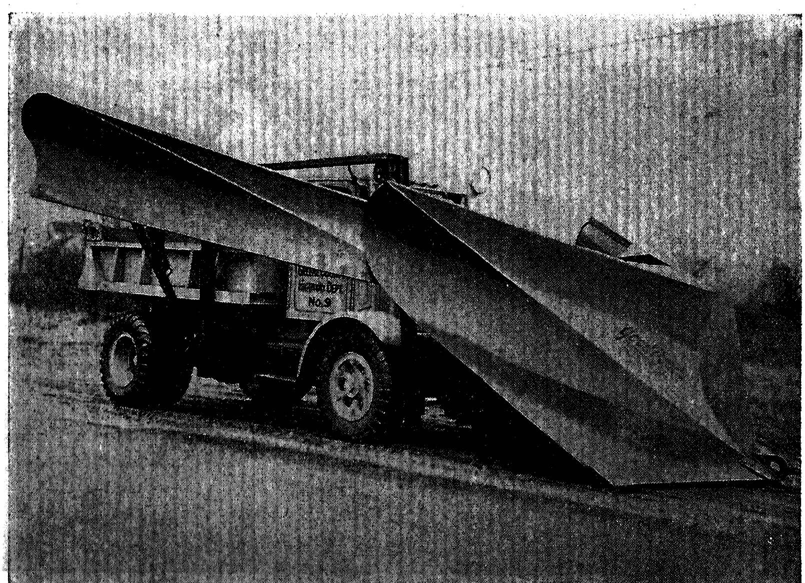


Fig. 1109. Welded steel snow plow. This construction assures maximum strength and rigidity for long life.

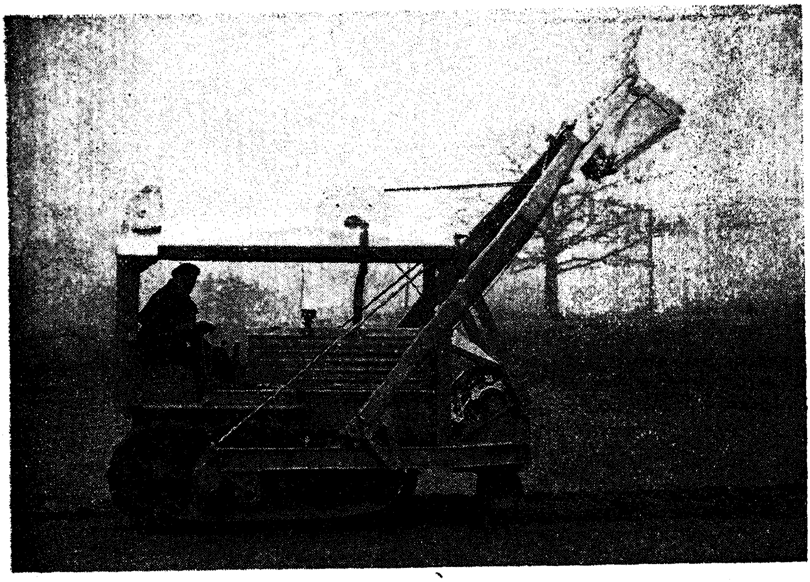


Fig. 1110. Overhead shovel mounted on standard tractor. This simplified welded steel design makes possible a wide range of applications.

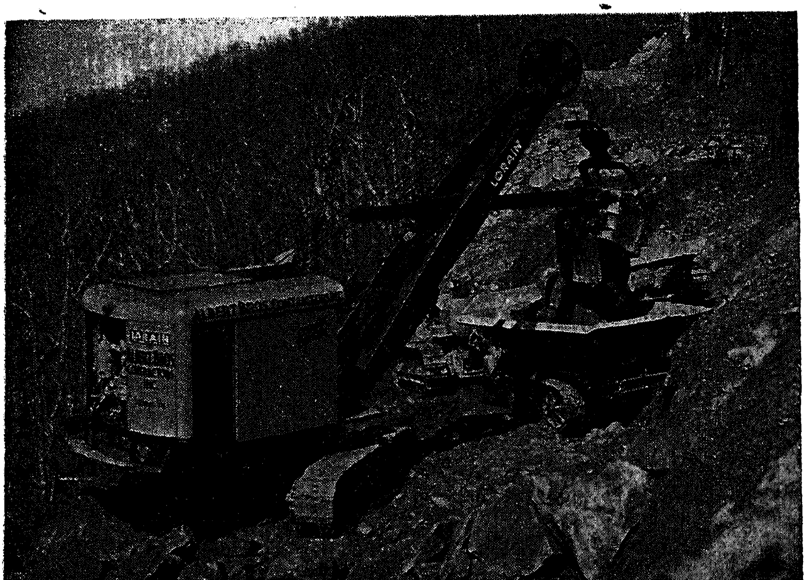


Fig. 1111. This new 1½ yard shovel features an all-welded 23-foot boom. Box beam construction provides the strength of plate girders with exceptional torsional rigidity. Dipper stick and cab also are welded.

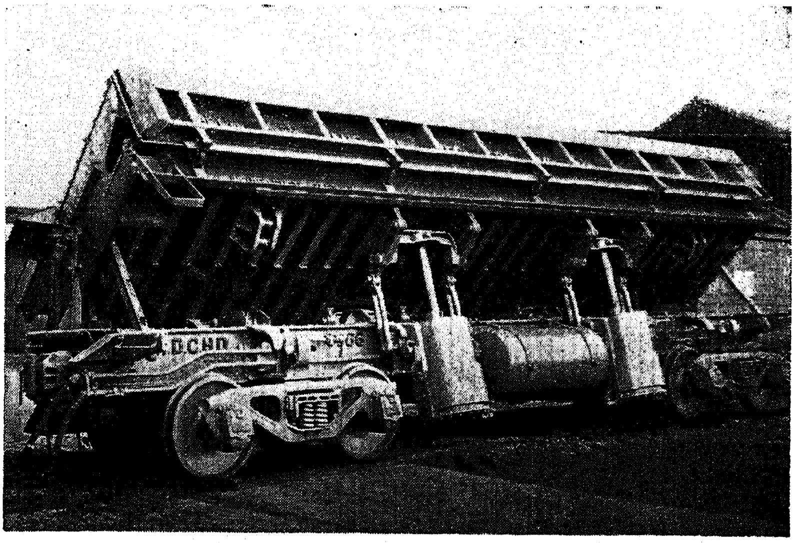


Fig. 1112. Dump car of arc welded steel construction. Weighs 12,000 lbs. less than conventional type of equal capacity. Remarkably smooth interior facilitates dumping and minimizes wear and corrosion.

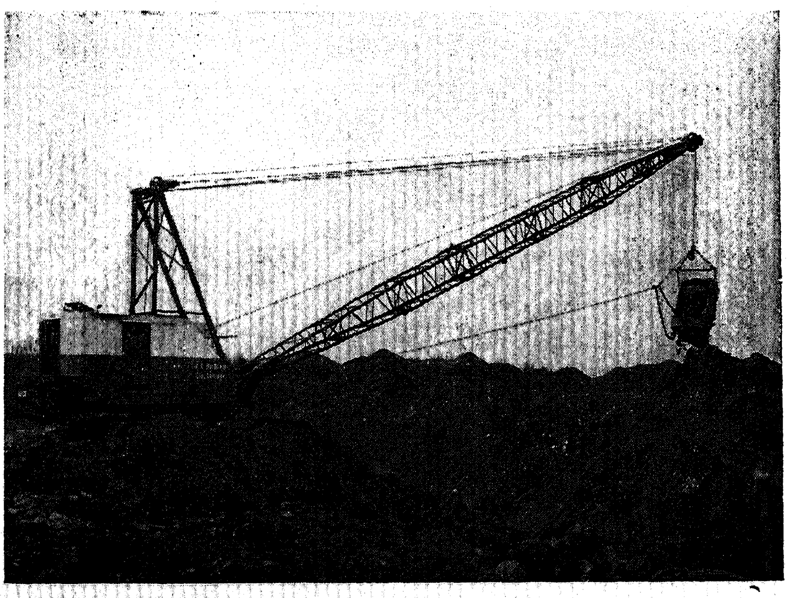


Fig. 1113. Drag line of all welded steel construction.

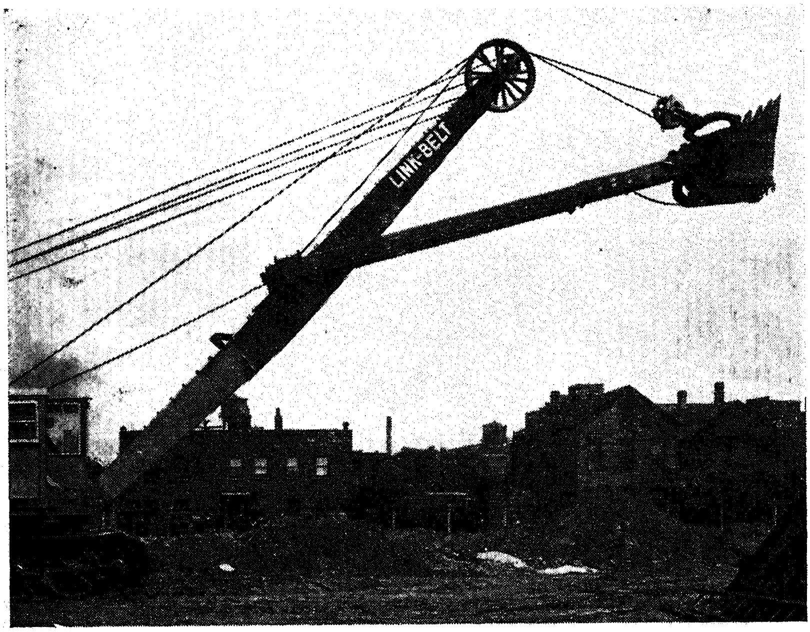


Fig. 1114. Crawler shovel equipped with all welded 36 ft. boom and 28 ft. dipper stick. The design eliminates "hog rods," affording greater stability and strength and saving 10% in weight over riveted construction.

Fig. 1115. All welded portable crushing plant. Length 36′ 6″, height 15′ 6″. Unusually strong, rigid, light weight construction.

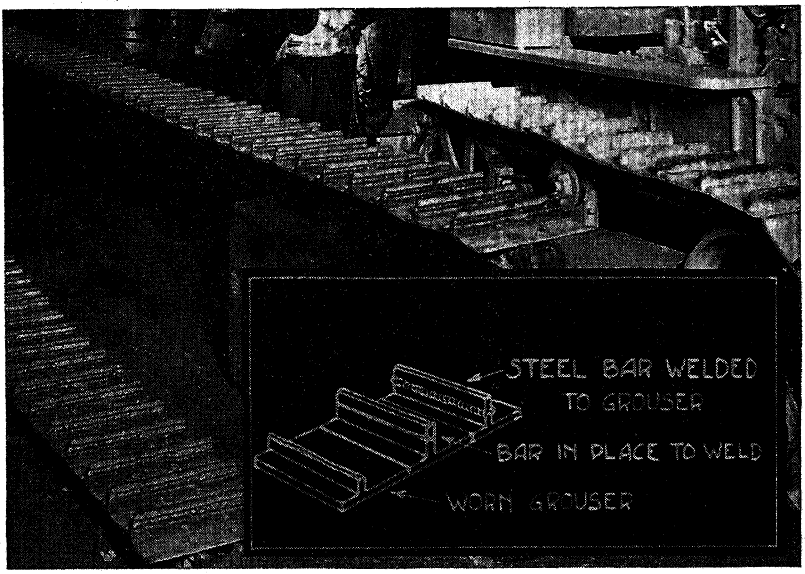


Fig. 1116. Building up tractor grousers by welding on medium carbon steel bars as shown in inset.

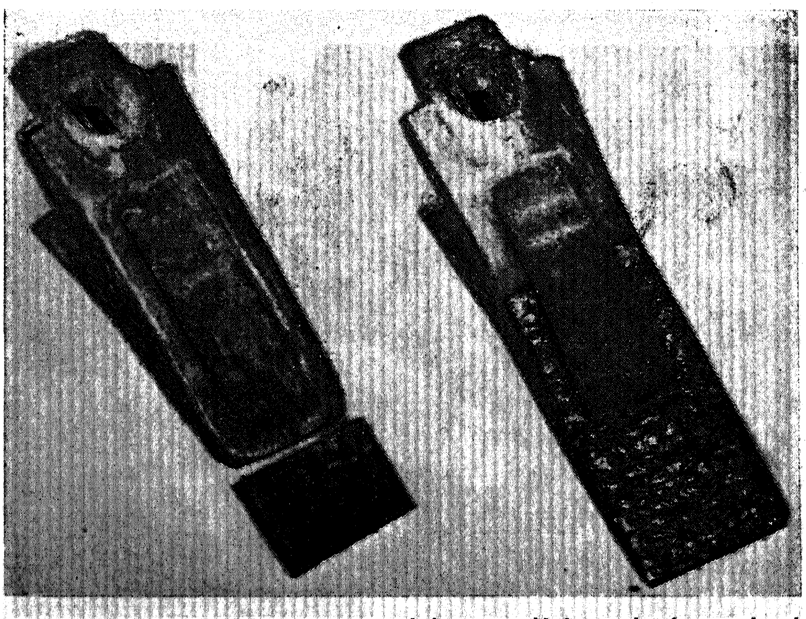


Fig. 1117. Here, special manganese steel tips are welded to ends of worn shovel dipper teeth with high manganese steel electrode. Worn portions of the tooth are built up with the same electrode. The wearing surfaces are then hard-faced with a semi-austenitic high carbon alloy steel electrode.

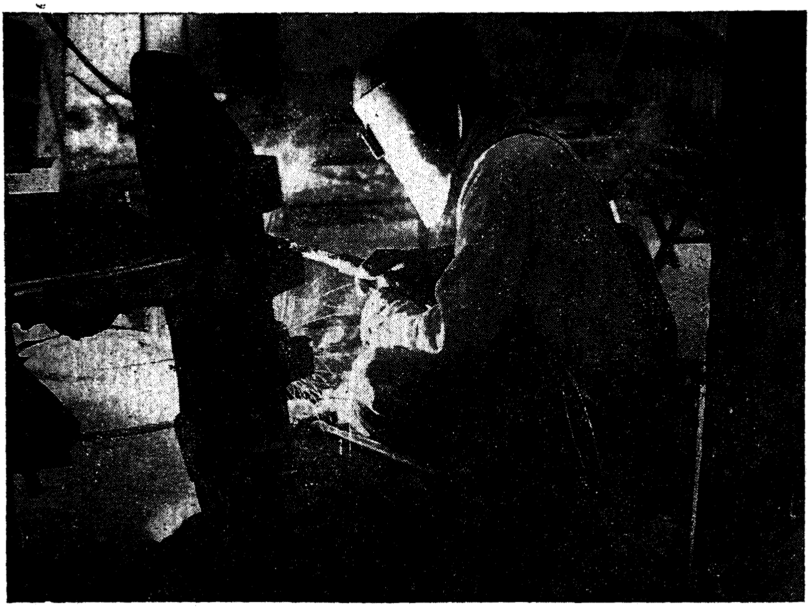


Fig. 1118. Building up worn surfaces of a power shovel track pad with high manganese steel electrode.

Fig. 1119. Repairing frame of Diesel tractor with mild steel shielded arc electrodes saving several weeks' delay.

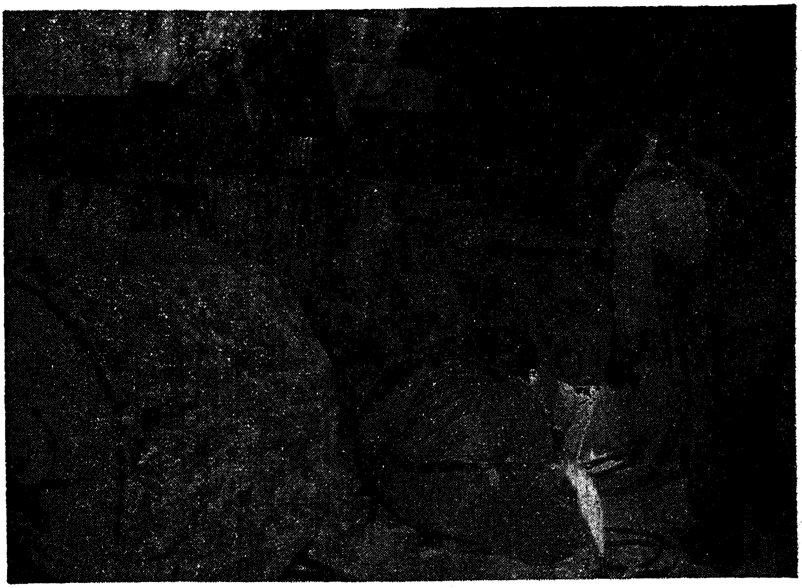


Fig. 1120. Repairing broken sprocket on a power shovel. Break was chipped to a vee and welded with 18-8 stainless steel electrode.

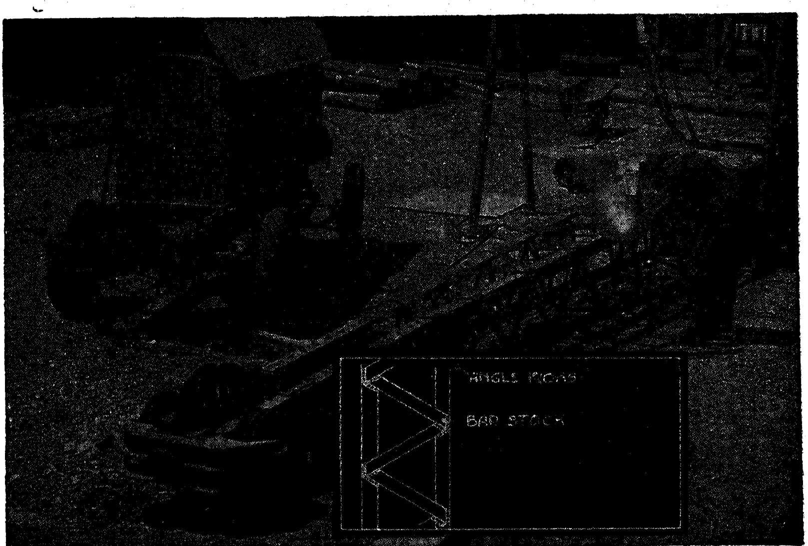


Fig. 1121. Repairing a drag line boom by replacing old riveted lattice members with welded on bars.

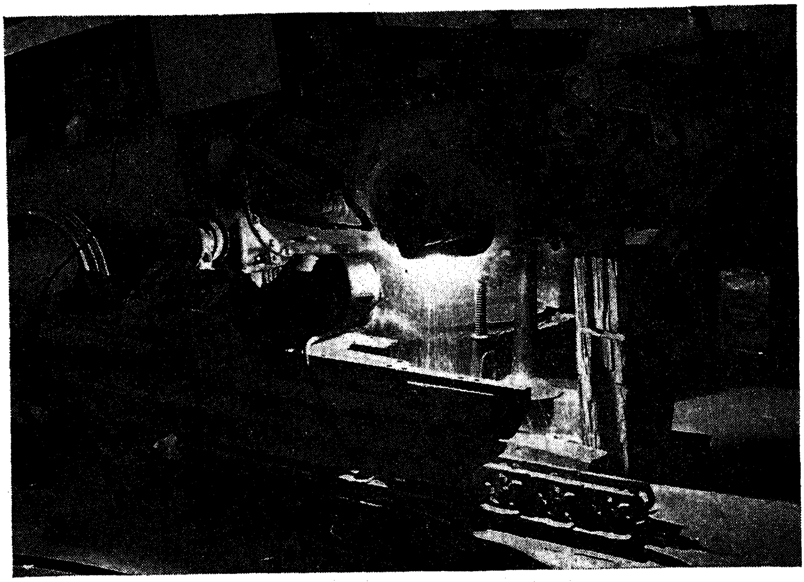


Fig. 1122. The cast iron transmission case of this 50 hp. crawler tractor was broken almost in two. It was welded with shielded arc cast iron electrode saving $200 and much outage time.

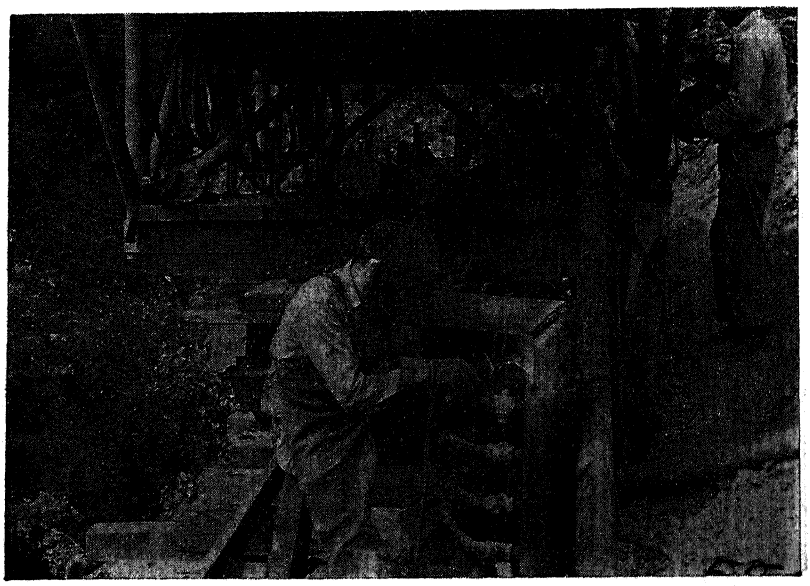


Fig. 1123. Welding a pipe elbow into a manifold for a drilling "jumbo" for a tunnel on a large dam project in the west.

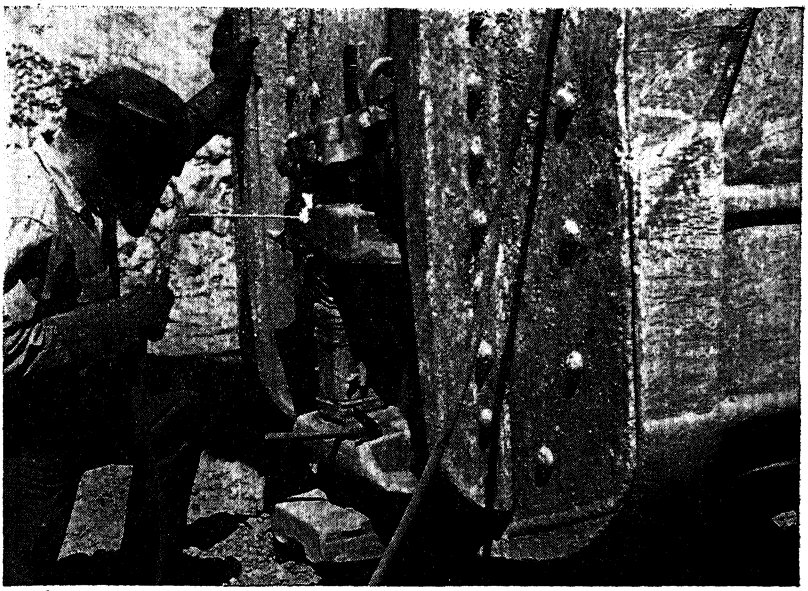


Fig. 1124. Repairing a broken trip on a five-yard shovel bucket with shielded arc mild steel electrode. Note also welded repair in lip of bucket.

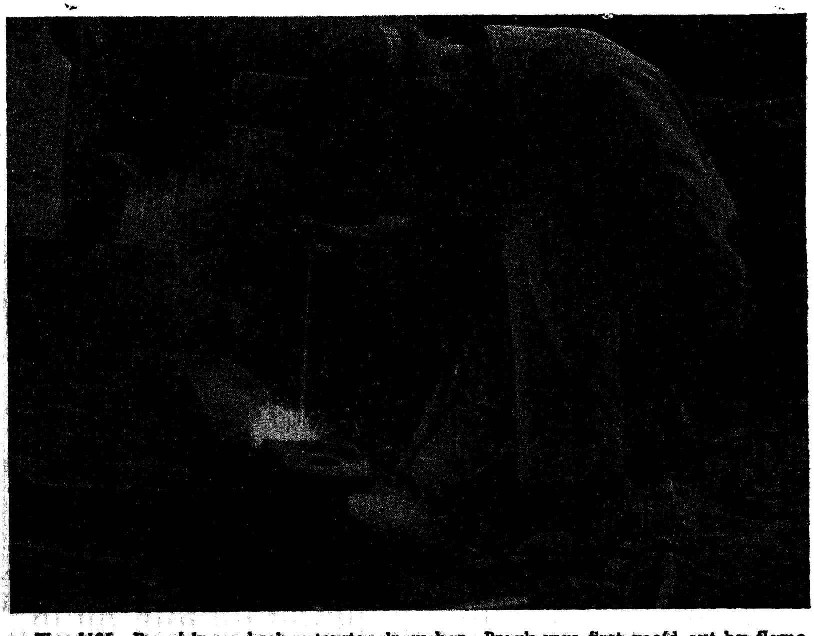


Fig. 1125. Repairing a broken tractor draw bar. Break was first vee'd out by flame cutting. First layer was made with 18-8 stainless steel electrode. Weld was finished with high tensile steel electrode. Welded from both sides.

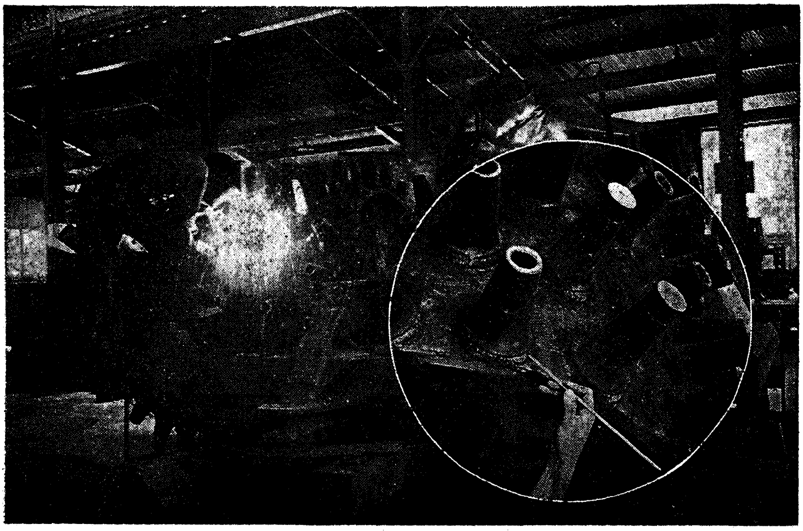


Fig. 1126. Welding on new feet on tamper used in dam construction. Old worn feet were cut off with cutting torch. New feet are welded on with two passes of shielded arc mild steel electrode. See inset.

Fig. 1127. Dredge pump impeller. Left shows worn surfaces, gauged out by sand abrasion. Right: After building up with mild steel electrode and hard-facing with super abrasion resistant electrode.

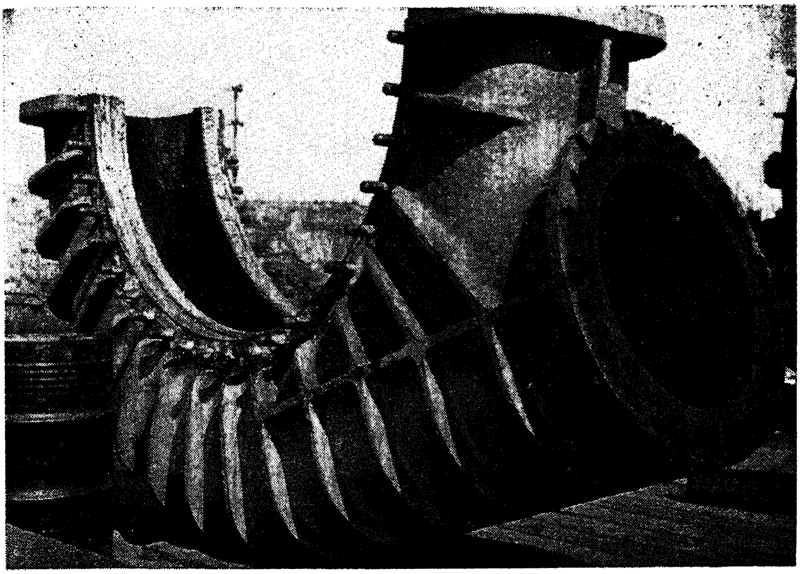


Fig. 1128. Half of a dredge pump casing. Worn cavities are built up with mild steel electrode and hard-surfaced with tool steel electrodes.

Fig. 1129. Dredge cutter head. Left: Worn head. Right: Head after blades were refaced with abrasion resisting electrode. Saved $720.00 over replacement. Hard-faced blades last 33% longer than new ones.

Farm Implements

Like construction machines, farm implements are subjected to relatively severe service, resulting in constant wear and frequent breakage of parts. For this reason, and for manufacturing economies, more and more of this equipment is being changed over to welded steel construction. This assures stronger parts and more rigid, serviceable assemblies.

Arc welding is also used extensively in the servicing of this equipment. Worn parts, hardfaced, include plow shares, cultivator spades, plow discs, mill hammers, planter runners, lister shares, potato diggers, etc. Typical applications are shown in the following illustrations.

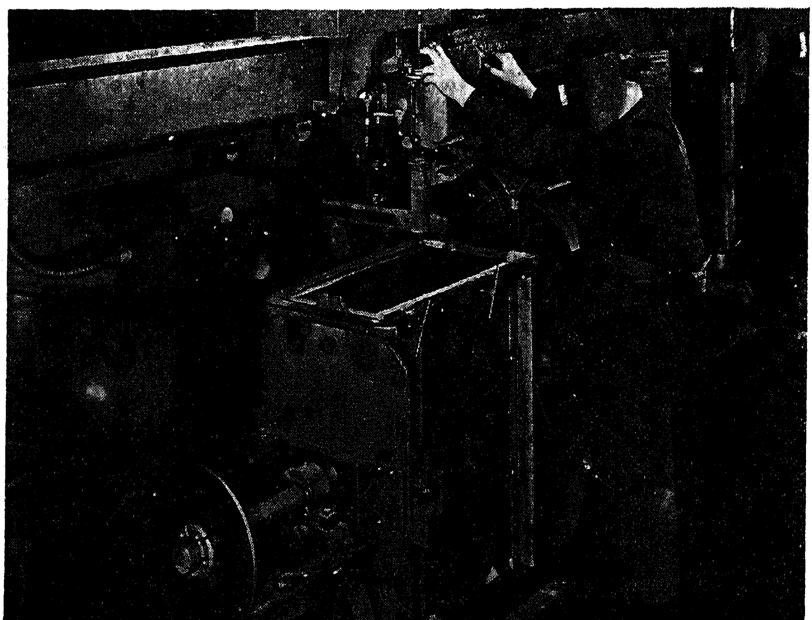


Fig. 1130. Fabricating main body of hammer mill by automatic carbon arc process.

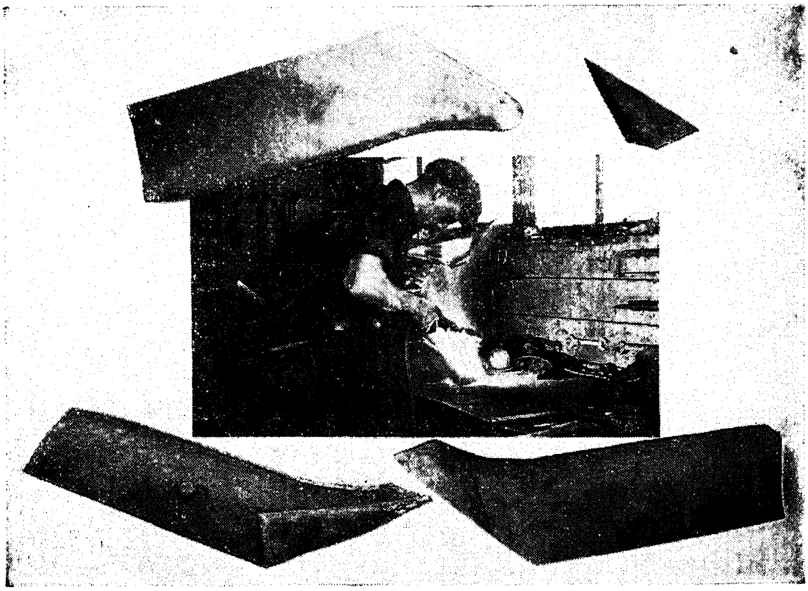


Fig. 1131. Reclaiming a plow share by arc welding. Top: Worn share with "new process" carbon steel tip which is welded on with mild steel electrode and hardfaced with semi-austenitic alloy steel as shown. Point and cutting edge are then hot-forged to sharpen. Result is shown at bottom.

Fig. 1132. Reclaiming worn cultivator shovels. Old points squared off. New points, cut from medium carbon steel plate as shown, are welded on with mild steel electrode. Cutting edges are hard faced with semi-austenitic carbon alloy steel electrode and hot forged sharp. Result shown in inset (two types of shovels).

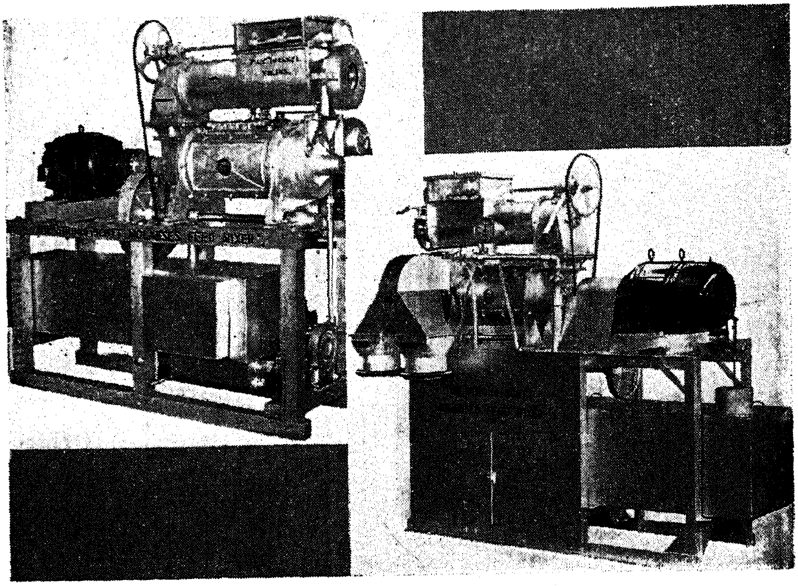


Fig. 1133. Molasses feed mixer. Left: Former construction with cast mechanism and wooden base. Right: Welded steel construction. Redesigned for welding resulted in a stronger, lighter and better looking product with cost savings of $72.00. Also misalignment troubles of the old base have been eliminated.

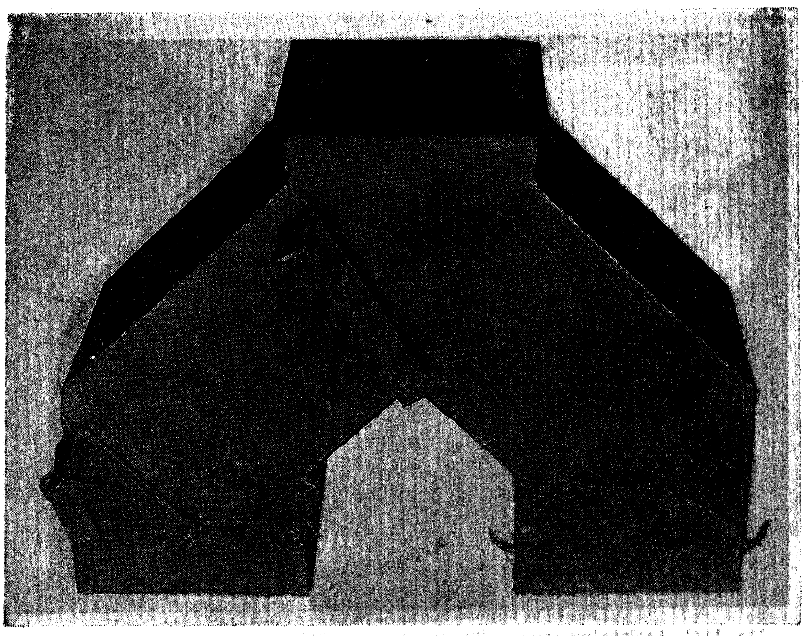


Fig. 1134. Grain mill spout used for filling sacks. Of all arc welded construction. A damper, operated by levers, controls distribution of grain to either side. Sacks are hung on hooks shown and lever releases hold when sack is filled.

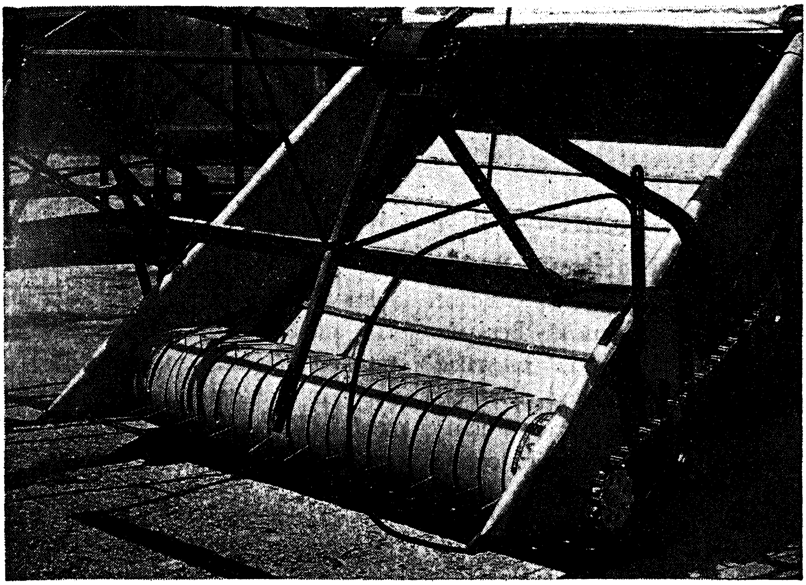


Fig. 1135. Combine pickup unit of all welded construction.

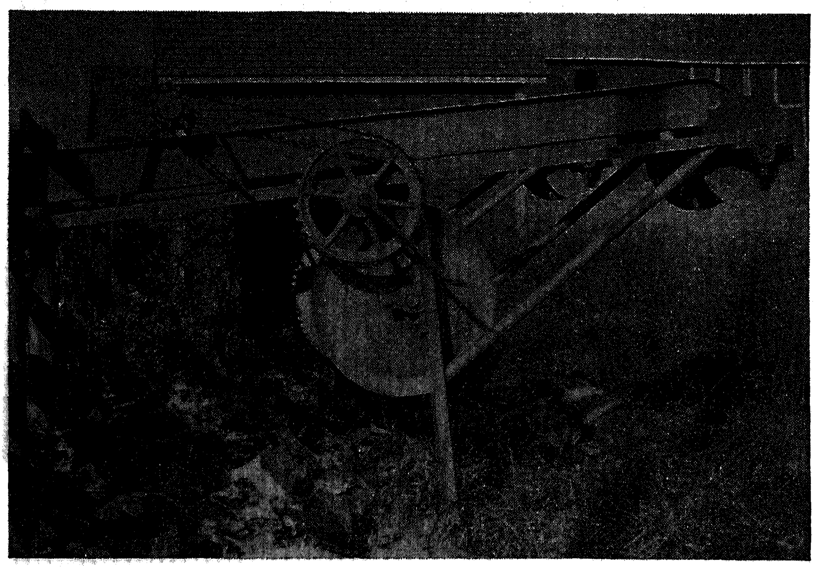


Fig. 1135A. This barn cleaner is typical of many special farm machines that can be built at low cost with welded steel.

Food Plant Equipment

The smooth lines and elimination of connecting members made possible by welded construction assure clean, sanitary conditions for food plant equipment. Because of this advantage, plus the economies through reduction in construction and maintenance costs, welding is being used more and more extensively in the design of food plant machinery, fixtures and structures of all kinds. A few typical applications are listed on the following pages.

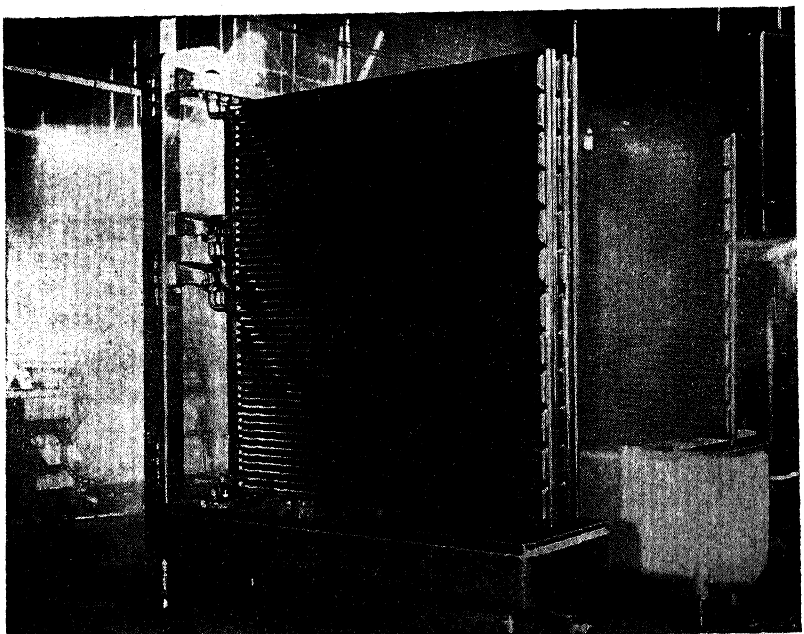


Fig. 1136. Partially completed milk cooler of all welded construction. Stainless steel throughout.

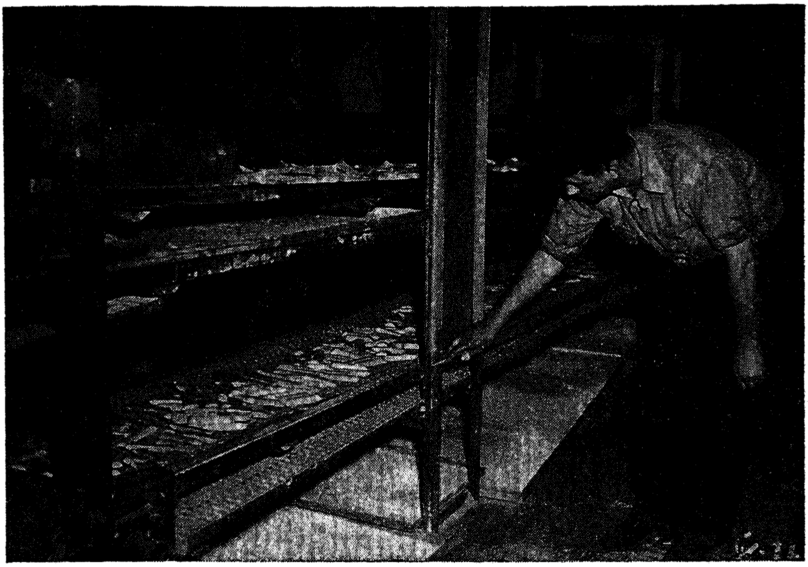


Fig. 1137. In a large candy plant. Framework for all conveyors in the plant is of welded construction.

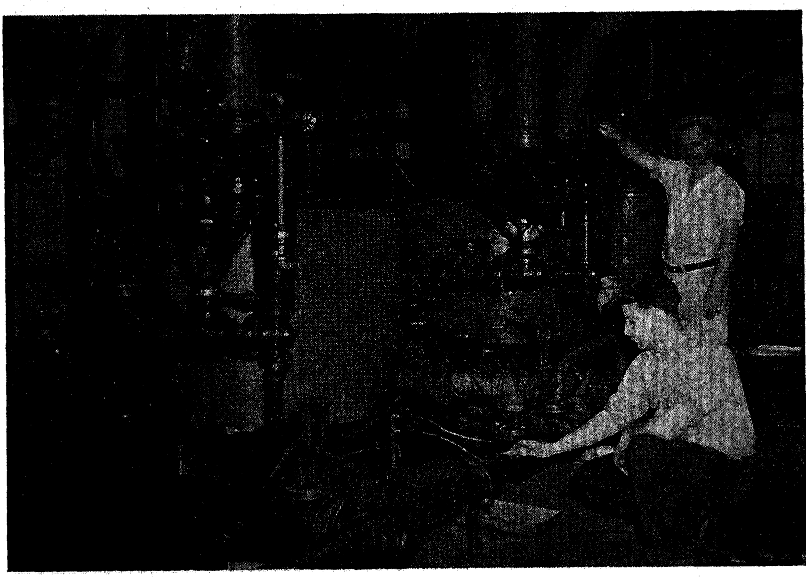


Fig. 1138. Piping in a large candy plant. Carries chocolate. All connections wherever possible are welded.

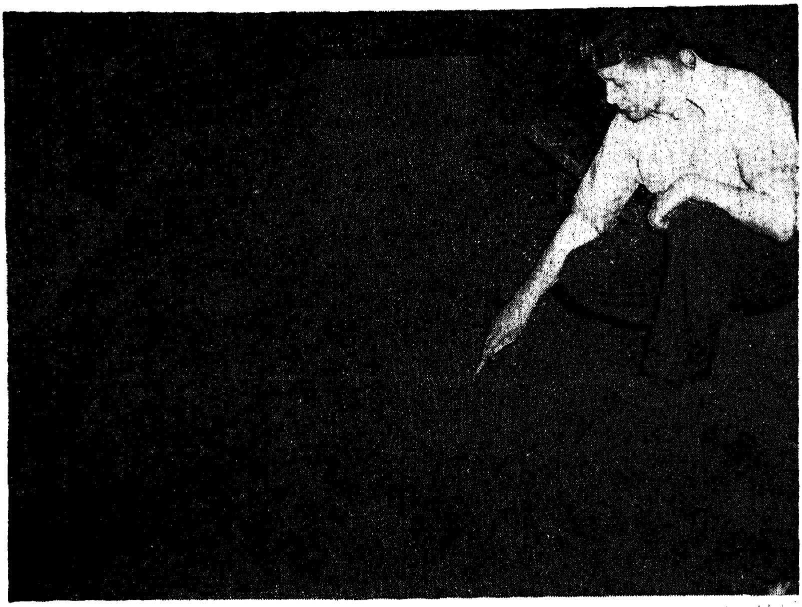


Fig. 1139. Floors, subject to wear by trucks, are covered with steel plate tack welded together as shown. Many food plants employ this construction.

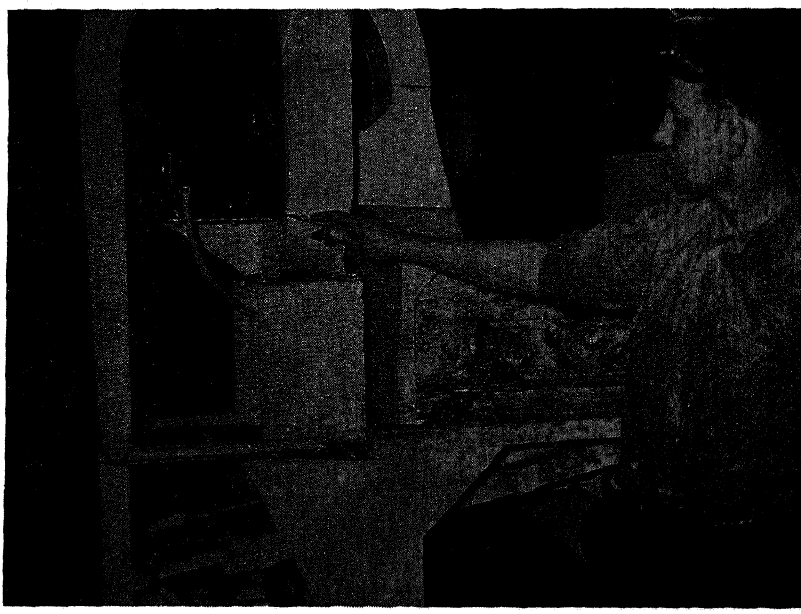


Fig. 1140. Special machine parts, mounting brackets and fixtures are fabricated in the welding shop of this large candy plant, using sheet metal, plate and shapes.

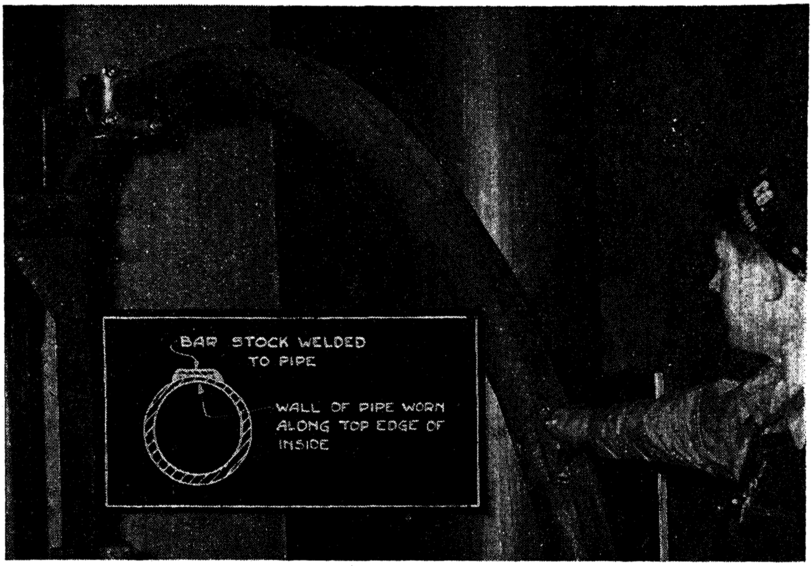


Fig. 1141. The top wall of this grain pipe, worn thin, was reclaimed by welding a steel bar along the edge as shown.

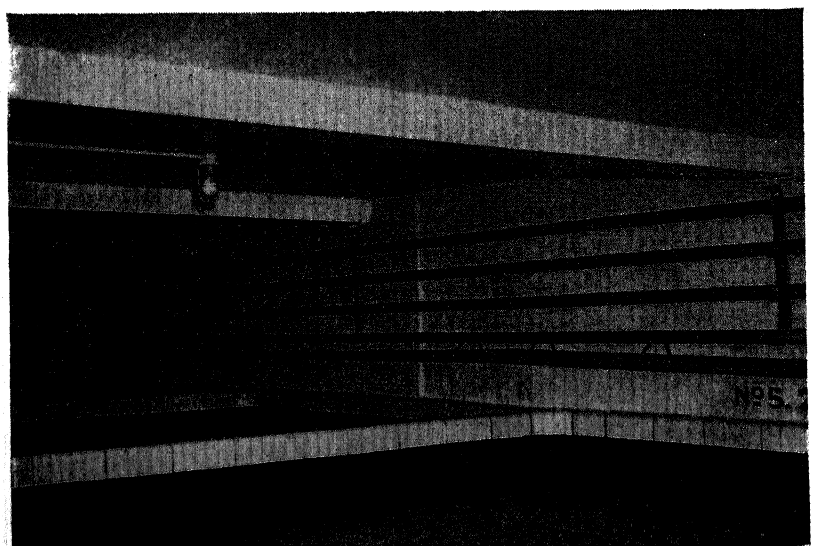


Fig. 1142. Refrigerant piping in the cooling room of a large brewery. The tanks in the foreground also are welded.

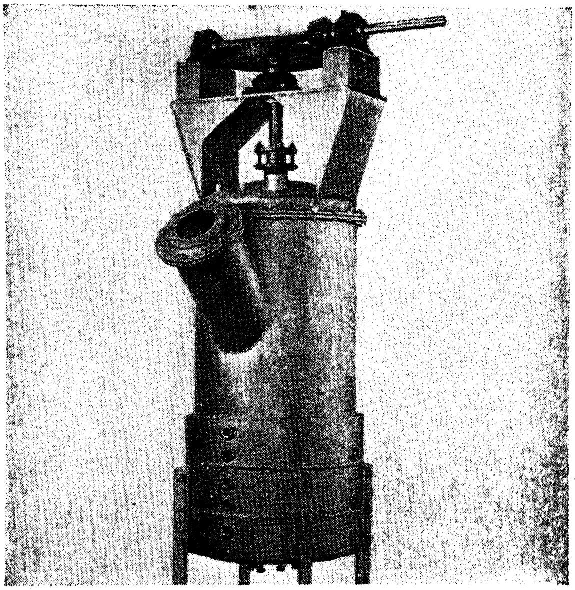


Fig. 1143. Welded stainless steel mixer for vegetable oils. Outer jacket is made of steel.

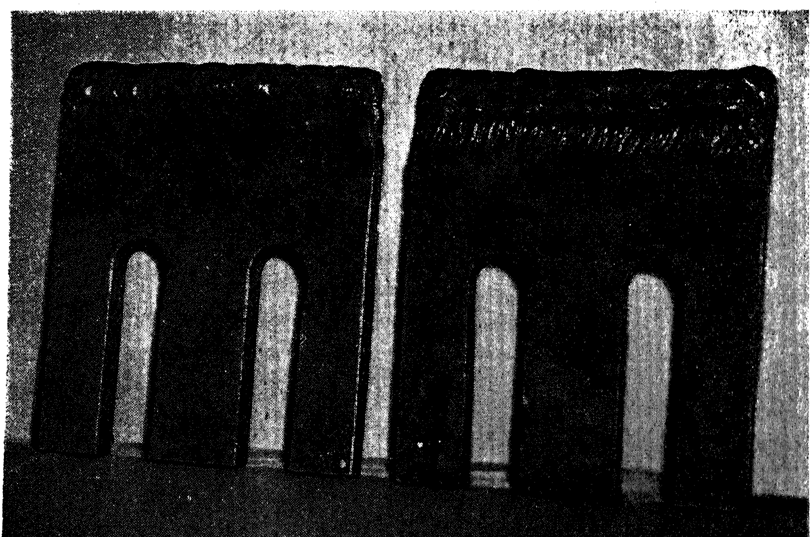


Fig. 1144. Bone cutter knives used by a meat packing plant. Worn face built up with mild steel electrode as shown on right. Cutting edge on front and on back (left) hard-faced with several passes of tool steel electrode. Knives are then ground to a sharp point. Saving for a set of 16 knives approximately $22.00.

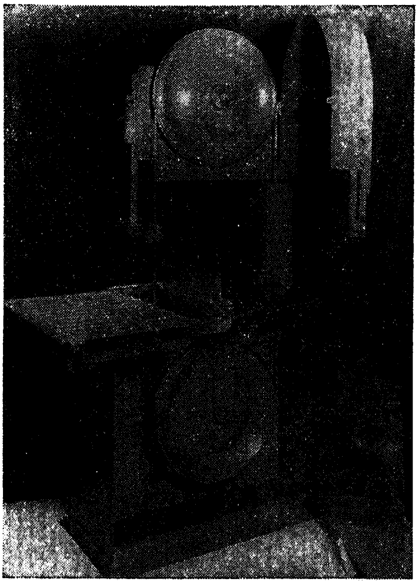


Fig. 1145. Meat and fish slicer of arc welded steel construction.

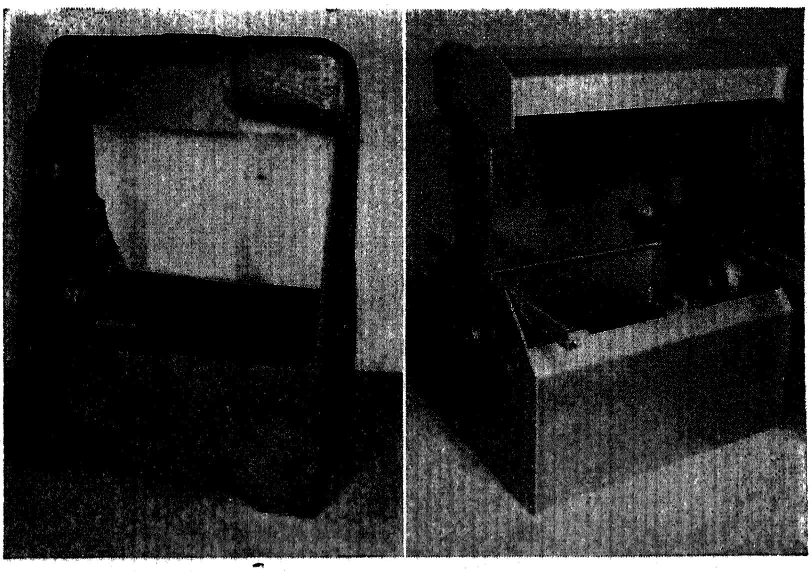


Fig. 1146. Changeover of the frame of this bread-slicing machine from casting to welded steel saved 60 sq. in. floor space, reduced weight 30%, increased accuracy of bearing alignment, saved 30% in manufacturing cost and improved sales.

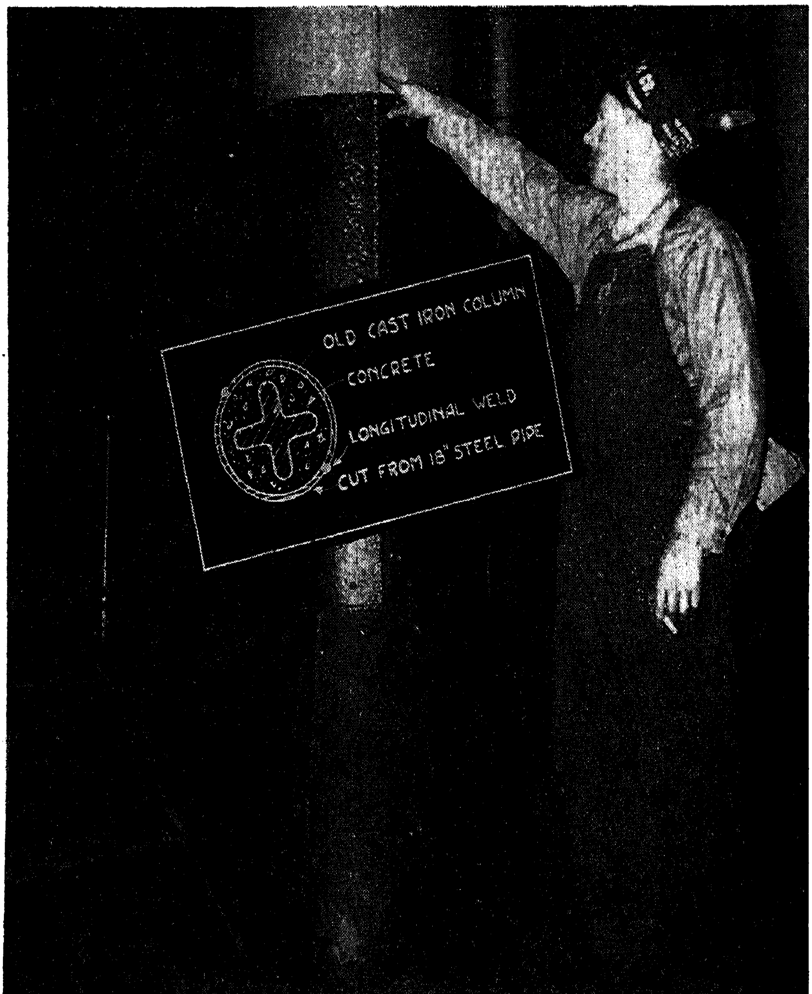


Fig. 1147. Main columns in a four-story brewery building of cast iron construction were reinforced by encircling with 18" steel pipe, split longitudinally and welded. Space between pipe and column was filled with concrete.

Furnaces and Heating Equipment

In the fabrication of steel furnaces and other welding equipment, arc welding is the preferred fabrication process because it makes possible seamless construction, having the ability to withstand pressure, corrosion and rapid variations in temperature. Contamination of the heated air by gases, soot or ashes is impossible with this seamless construction. Welds made by the shielded arc process are more resistant to the corrosive action of sulphurous gases than even the base metal. Because less preparation of parts prior to assembly is necessary when welding is employed, it is also the most economical fabricating process. Many widely varied types of furnaces and boilers are built of arc welded steel construction. These include coal and gas fired domestic furnaces, heating boilers, and furnaces for heat treating and other industrial uses. A few examples of these products built of steel by the electric arc are illustrated in Figs. 1148 to 1154.

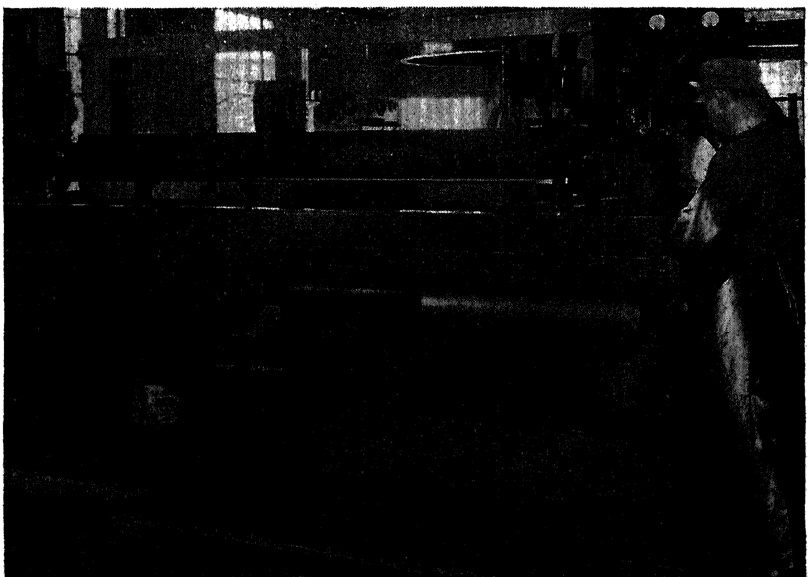


Fig. 1148. Welding longitudinal seams in combustion chamber for a gas furnace with automatic carbon arc welding. The same set-up is used in this plant for welding range boilers.

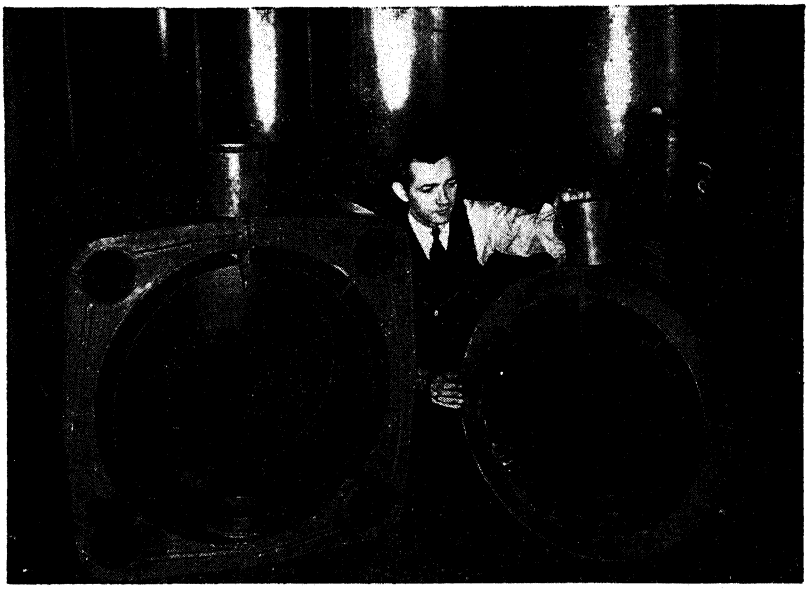


Fig. 1149. Two types of combustion drums of all arc welded steel construction. Thickness of sheet is 16 to 20 gauge.

Fig. 1150. Welding the flue section of domestic furnaces. This is mostly 12 gauge sheet.

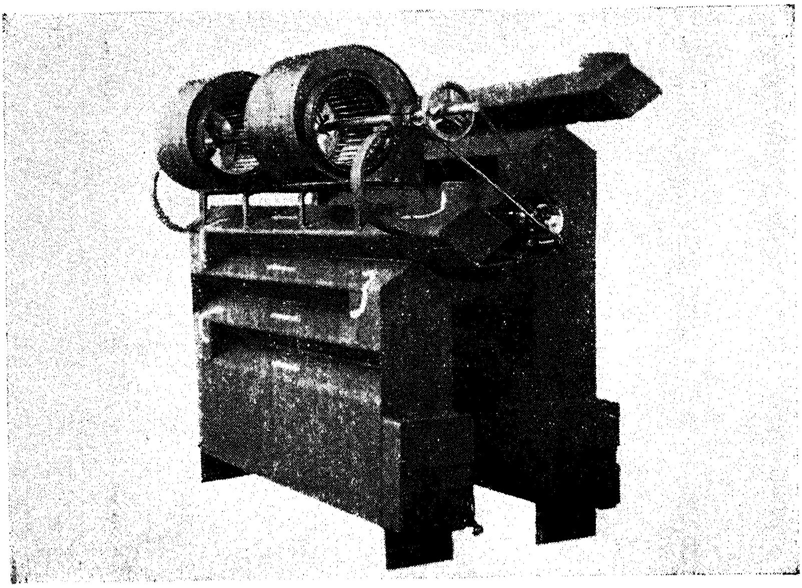


Fig. 1151. A gas fired hot air furnace of arc welded steel construction used for the heating of an industrial plant.

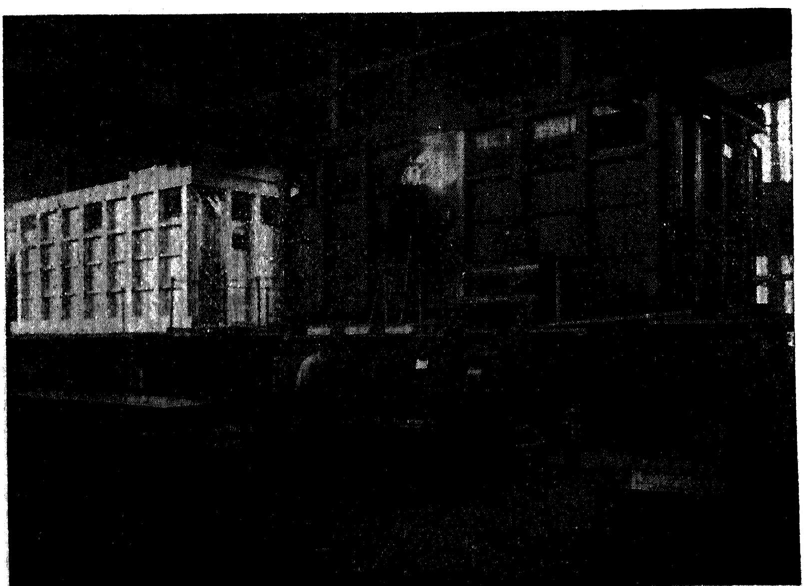


Fig. 1152. Annealing cover for heat treatment of steel. Entirely arc welded from steel plates and shapes. Weight 35,000 lbs.

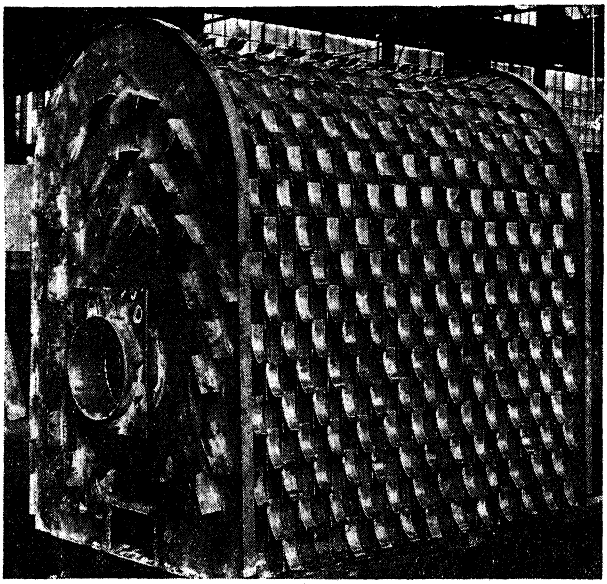


Fig. 1153. Combustion chamber for shop heater of arc welded steel construction. Welding made possible unusual design of fins. Heating efficiency 87%.

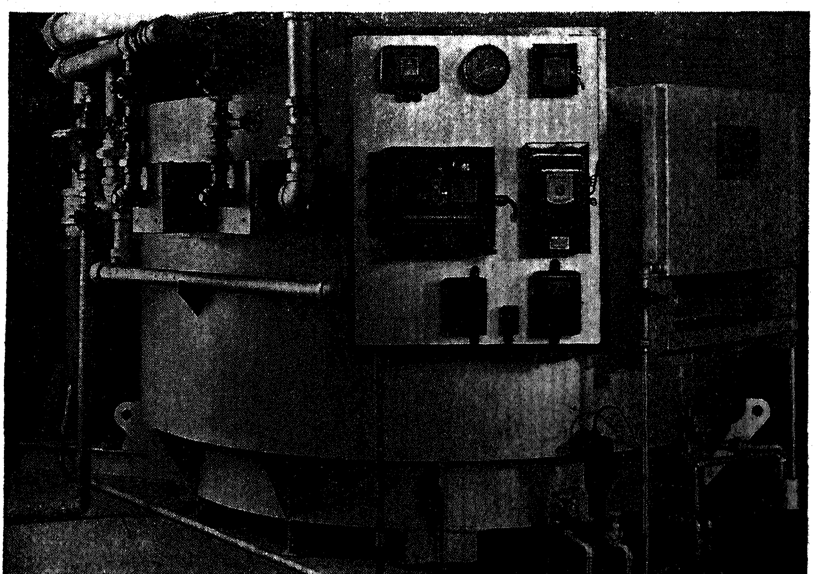


Fig. 1154. Rotary forging furnace with water seals and syphon vents. Diameter 7 ft.

Gas Plant Equipment

Purifiers, water gas generators, coke pushers, piping, cylinder heads, moisture eliminators and valves are a few of the many pieces of gas plant equipment which are fabricated by arc welding for strength, rigidity, tightness and minimum weight. A few of these applications are here illustrated.

Arc welding also serves gas plants as a valuable maintenance tool, providing a means of servicing to resist erosion and abrasion, and of fabricating special structures and replacement parts of existing machinery. These applications include water and steam piping, glass piping, tar treating equipment, coal bunkers, conveying systems, water tanks, pulverizer parts, generator parts and valves.

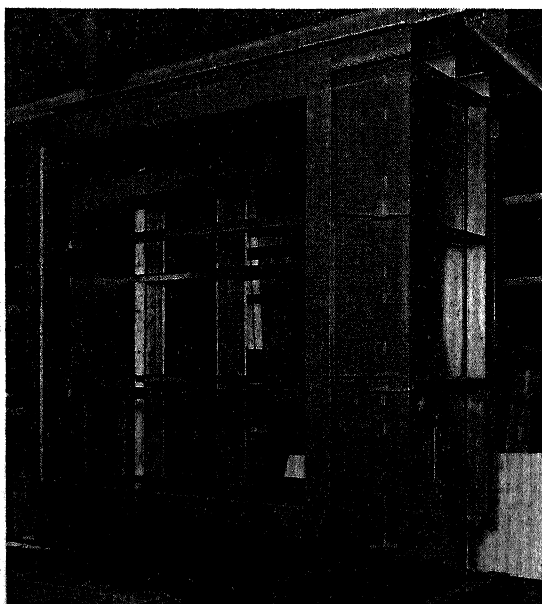


Fig. 1155. Moisture eliminator built by arc welding.

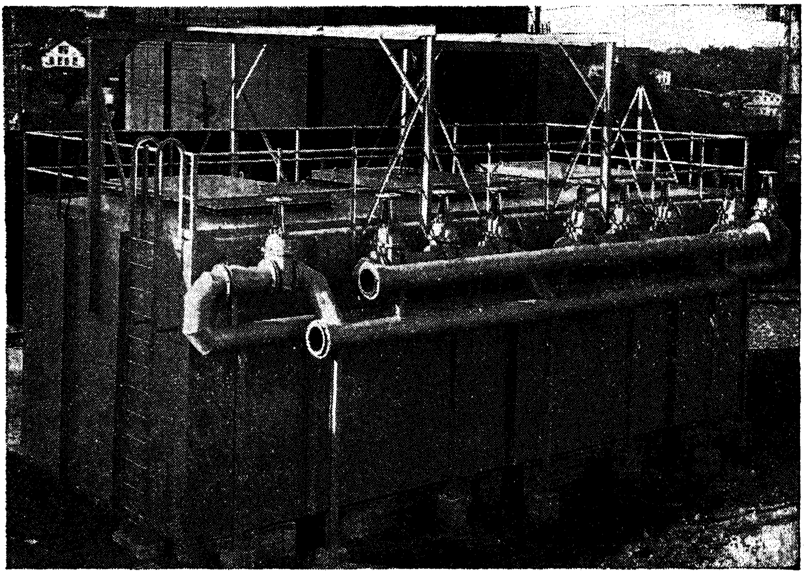


Fig. 1156. Gas purifyers of all welded steel construction. Exceptionally strong, rigid, light in weight, of pleasing appearance and permanently tight.

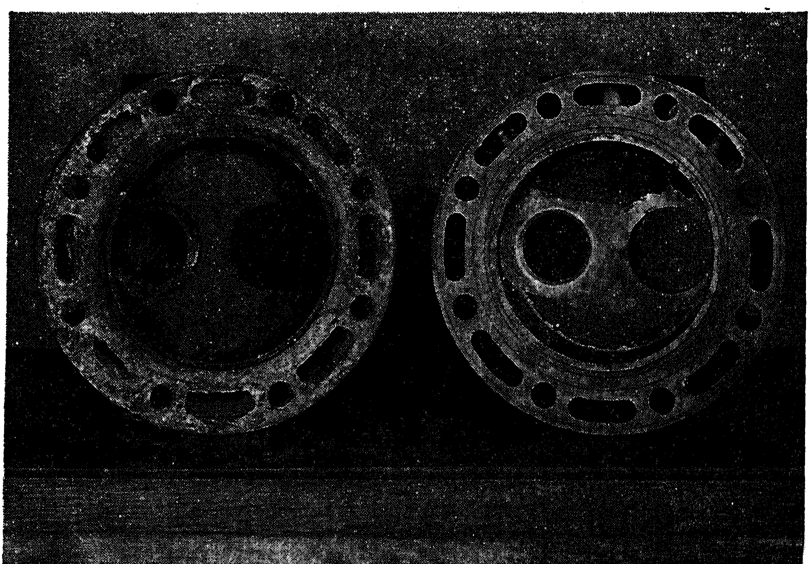


Fig. 1157. Cylinder head built from ordinary steel instead of expensive corrosion resisting steel. Left hand (port) opening — where corrosion normally occurs — is faced with 18-8 stainless steel electrode. Finished valve is shown on right.

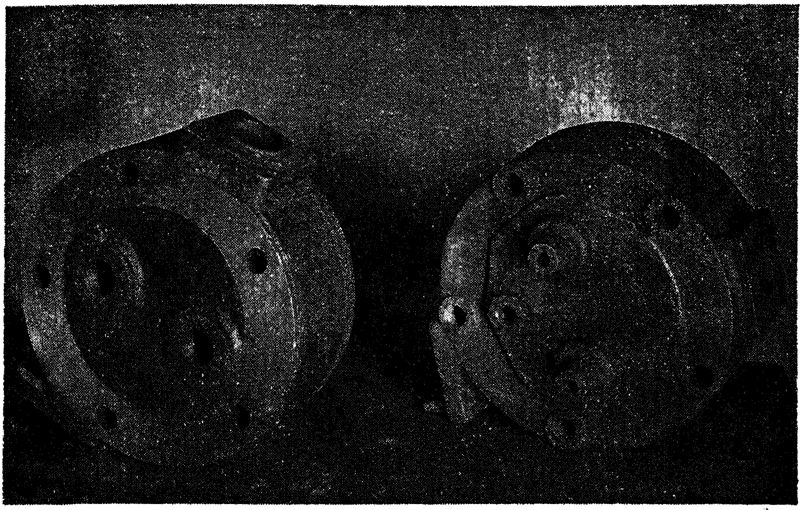


Fig. 1158. Fabricated welded steel cylinder head shown on left replaces cast head shown on right.

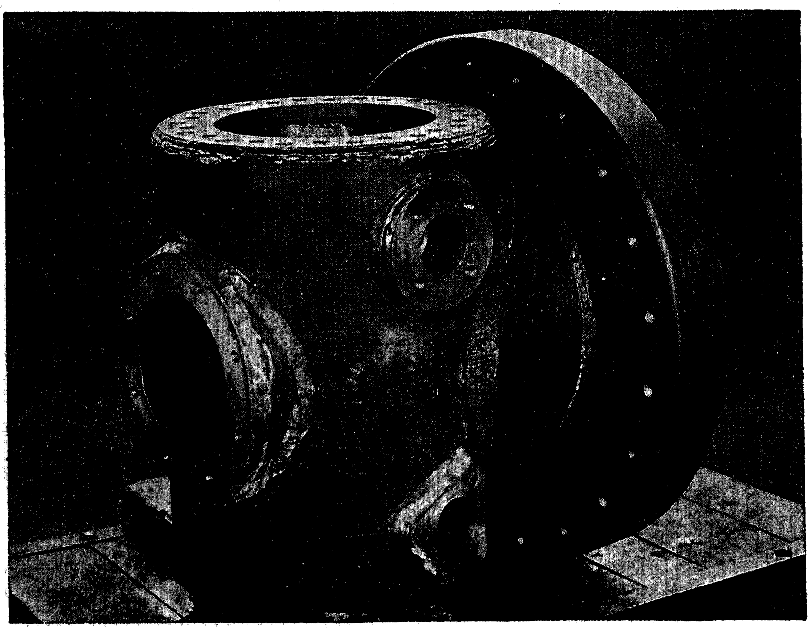


Fig. 1159. Cylinder head for large gas engine fabricated from steel plate and pipe. Weighs 1370 lbs. as compared to 1940 lbs. for the casting which it replaced.

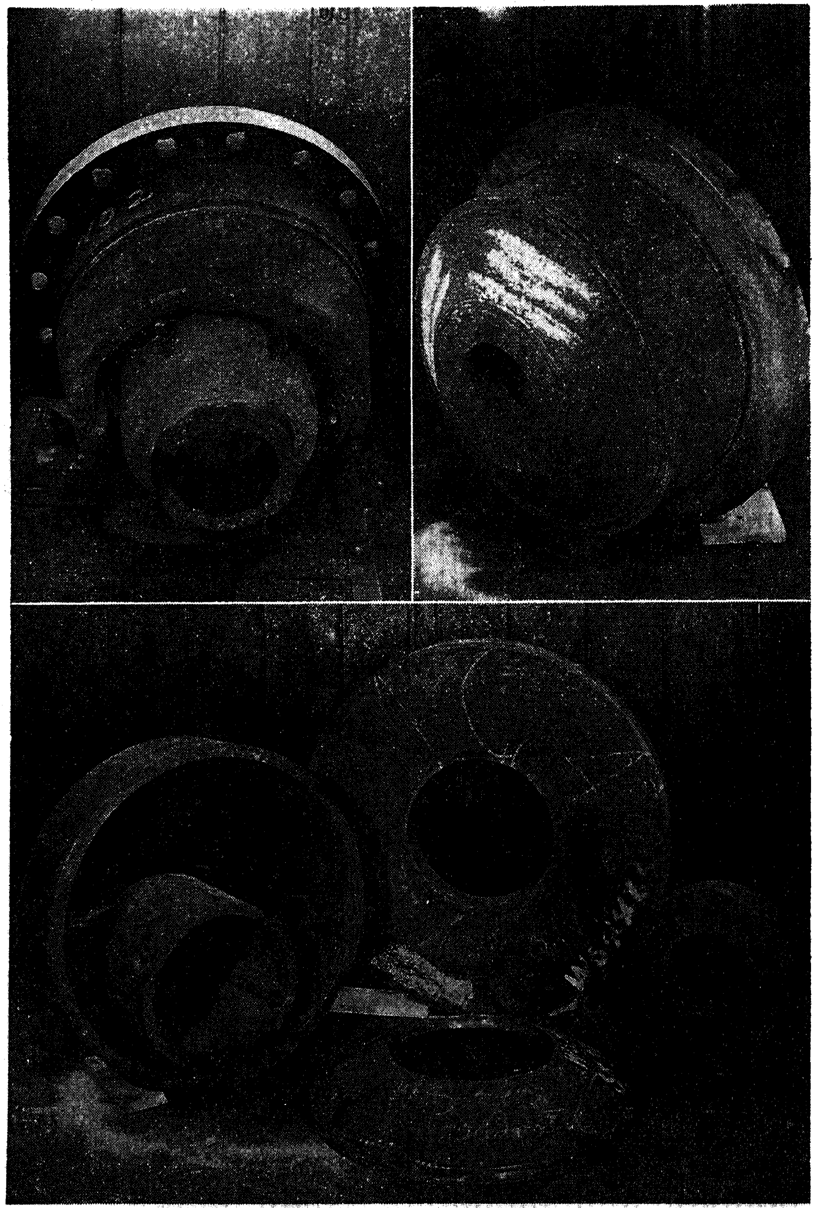


Fig. 1160. Frequent breakage of cast iron cylinder heads (left) due to lime deposits, are overcome by fabricating the heads from welded steel. Component parts are shown below. Finished head shown above at right. Welded throughout with shielded arc mild steel electrode. Material cost $119.00. Labor, welding and machining $83.00. Finished head weighs 975 lbs.

Household Equipment and Fixtures

Recent developments in the arc welding of light-gauge metals and alloys have resulted in the development of a wide variety of household equipment and fixtures. This includes furniture items, kitchen cabinets, sinks, furnaces (see Page 833), ranges, refrigerators, stokers and ornamental ironwork (see Page 935).

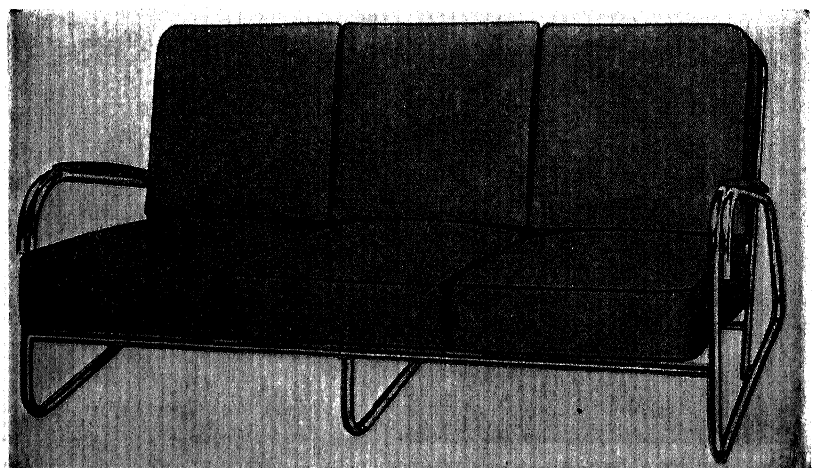


Fig. 1161. Chair and davenport of modern chromium tubular arc welded construction. Employs 18 gauge plated steel tube.

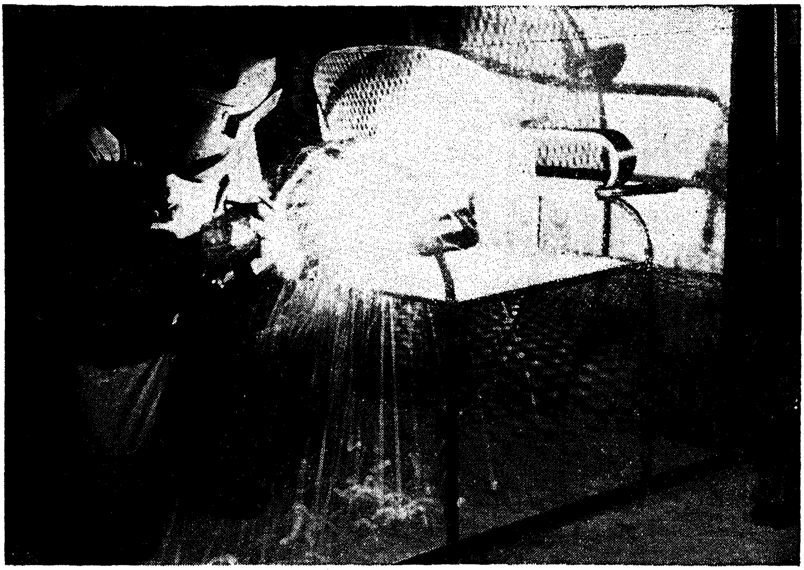


Fig. 1162. In the manufacture of all metal chairs and other pieces of furniture for outdoor service, this manufacturer saves as much as $30.00 a day in one operation alone by changeover from riveted and bolted construction to welded fabrication.

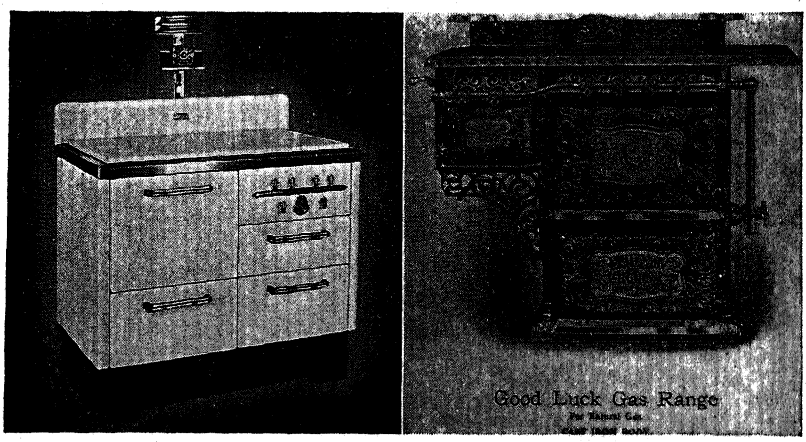


Fig. 1163. The old cast iron model and the latest welded steel model "Good Luck" gas range. Welded range shown has edge band of stainless steel made from three pieces of brake formed sheet at substantial saving over die-forming.

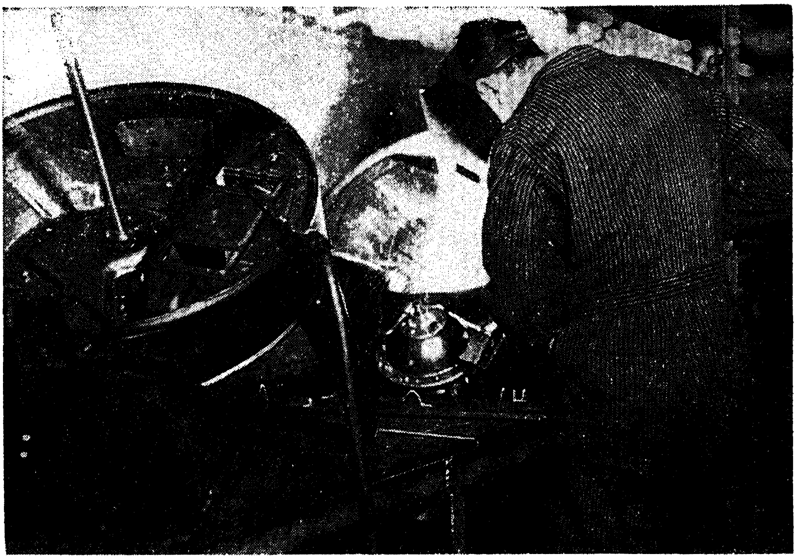


Fig. 1164. Arc welding the pressed steel framework for a washing machine. This construction is much more rigid and permanent than the bolted construction used formerly.

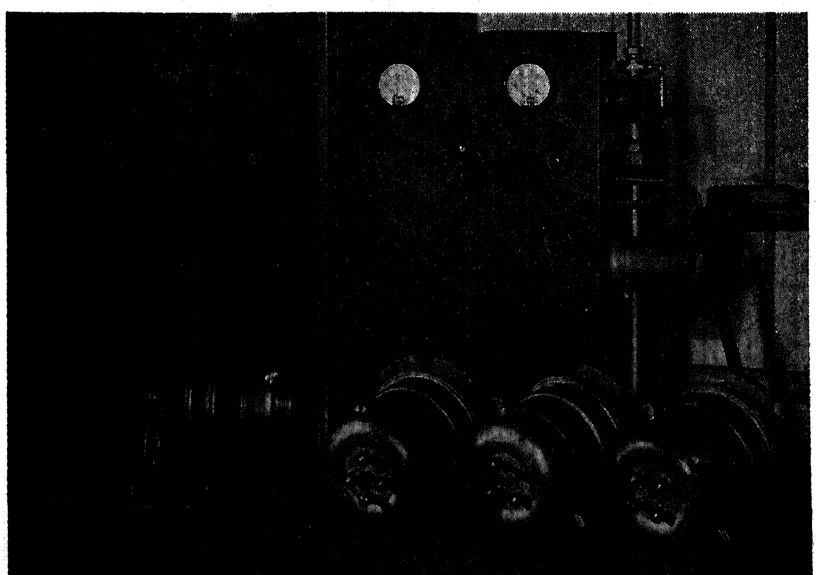


Fig. 1165. Refrigerator compressor shells, welded by automatic carbon arc process.

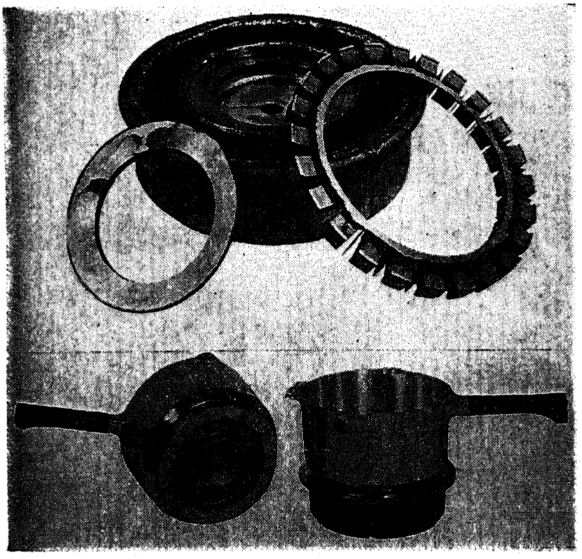


Fig. 1166. New type of electric cooking unit operating by induction rather than resistance. Arc welding makes its construction practical.

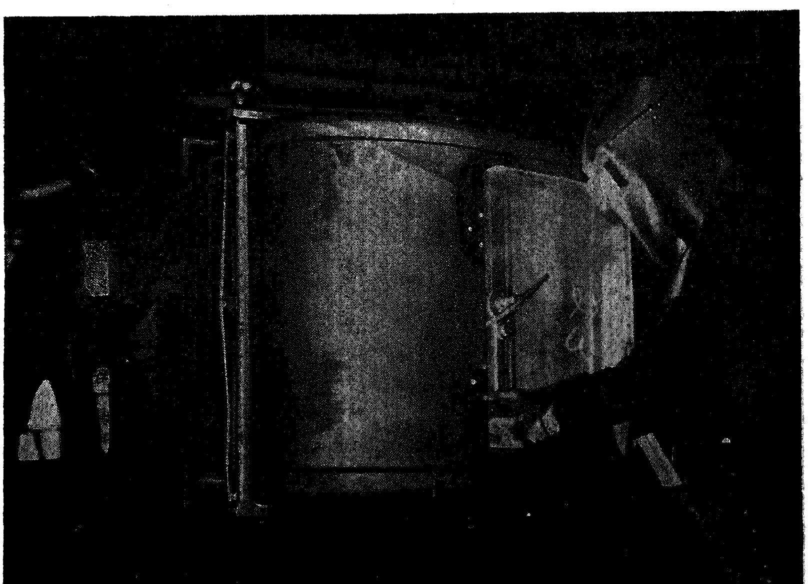


Fig. 1167. Fabricating domestic stokers from 16-gauge pressed steel parts by arc welding. Positioning jig with copper back-up fixture simplifies assembly.

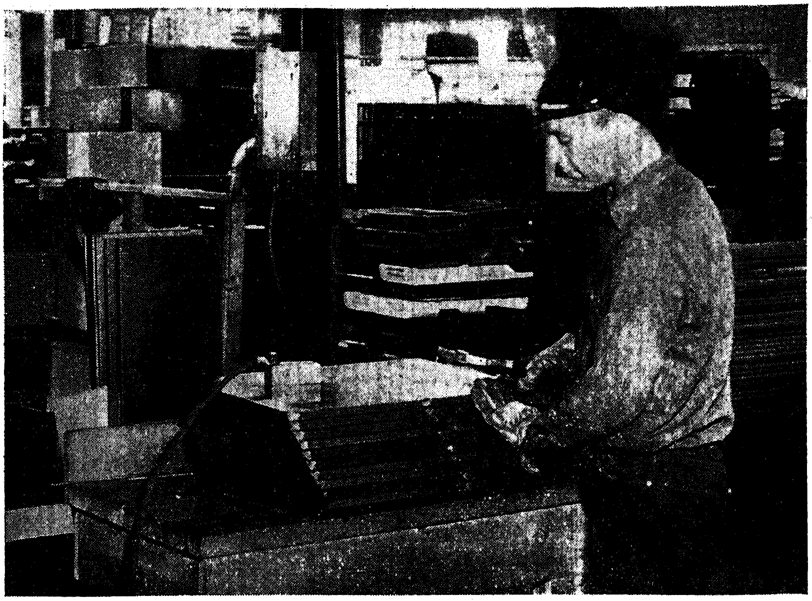


Fig. 1168. Arc welding cuts costs in the manufacture of kitchen cabinets. In this shop the electric welding process requires half as much welding rod, saves 75% in welding fuel cost and is 10% faster.

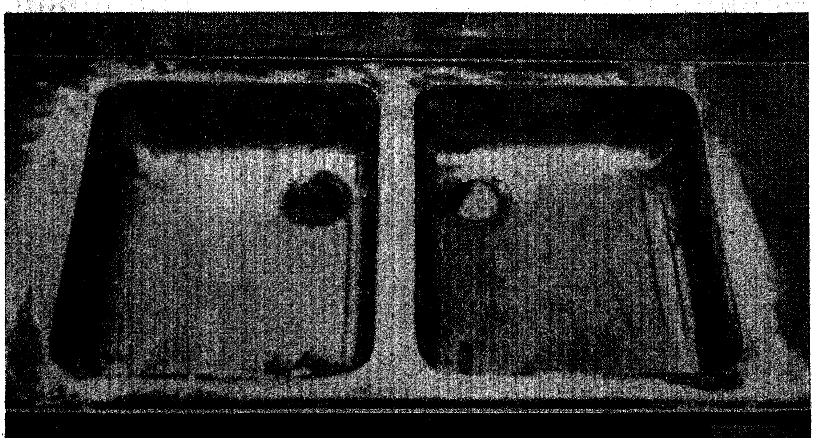


Fig. 1169. Twin-bowl kitchen sink, 12 ft. long, fabricated of monel metal by electric arc welding.

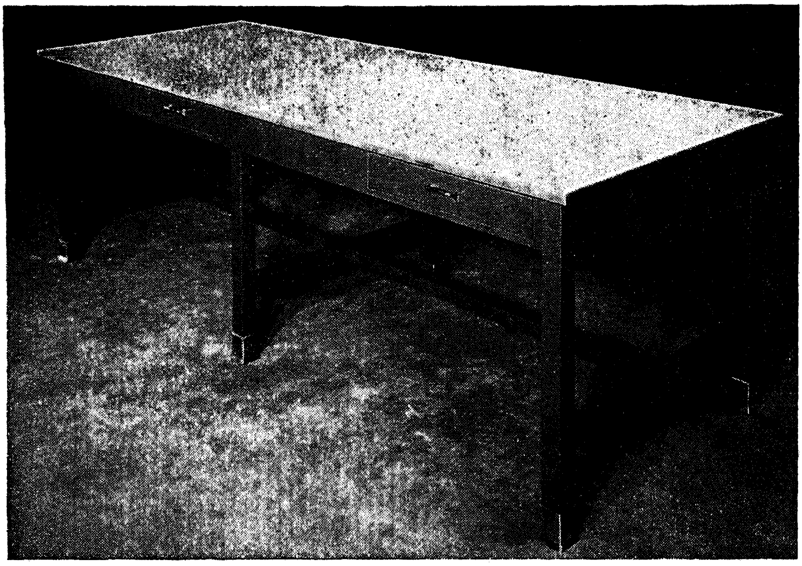


Fig. 1170. Laboratory table built from galvanized sheets welded by the carbon arc process with tinned copper alloy feeder rod.

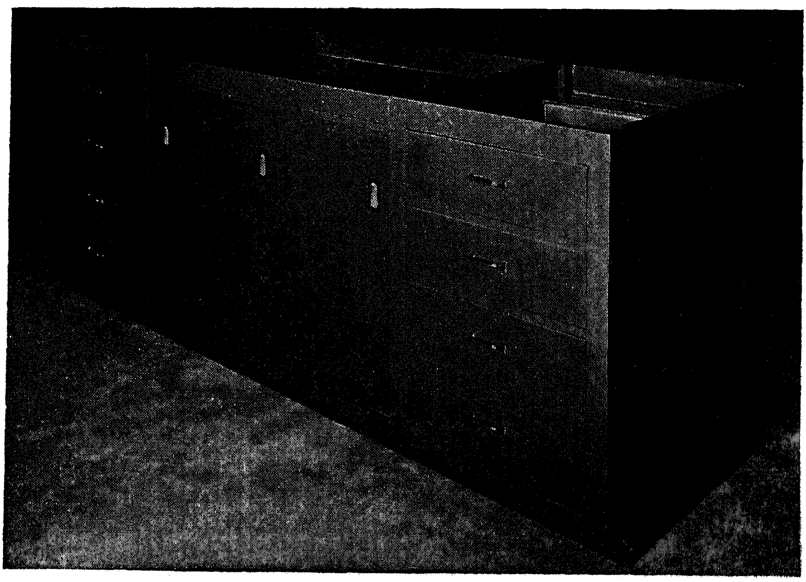


Fig. 1171. A laboratory cabinet built from galvanized sheets welded by the carbon arc process with tinned copper alloy feeder rod.

Jigs and Fixtures

Arc welding is a valuable aid to tooling in meeting today's requirements for mass production, affording outstanding economies. Among the advantages of welded steel jigs and fixtures are: Maximum strength, accuracy for closer tolerances, cost saving as high as 75%, time saving as much as 85%, weight savings as much as 50%, wider range of application, simplified designing, minimized machining, easy modification to meet design changes.

The accompanying illustrations show typical jigs and fixtures of arc welded construction.

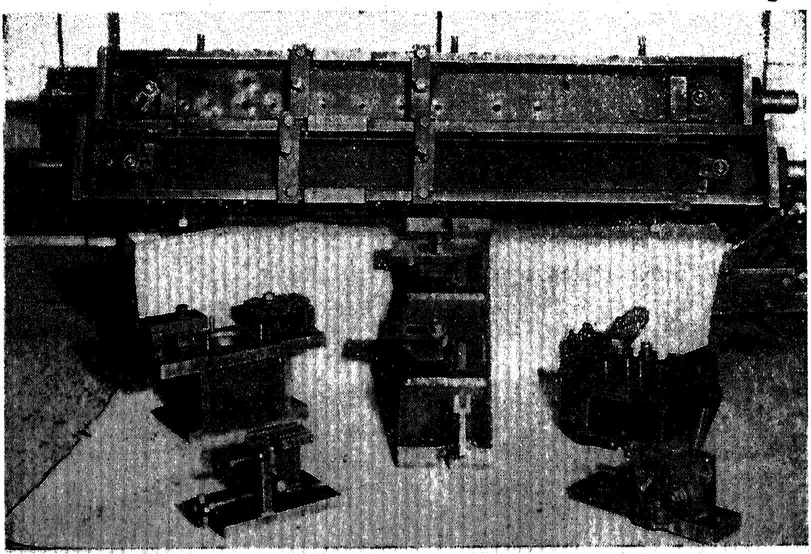


Fig. 1172. Welded steel fixtures used for cutting keyways in shafts. Welding saves 75% in cost, the top two fixtures being welded at savings of $28.00.

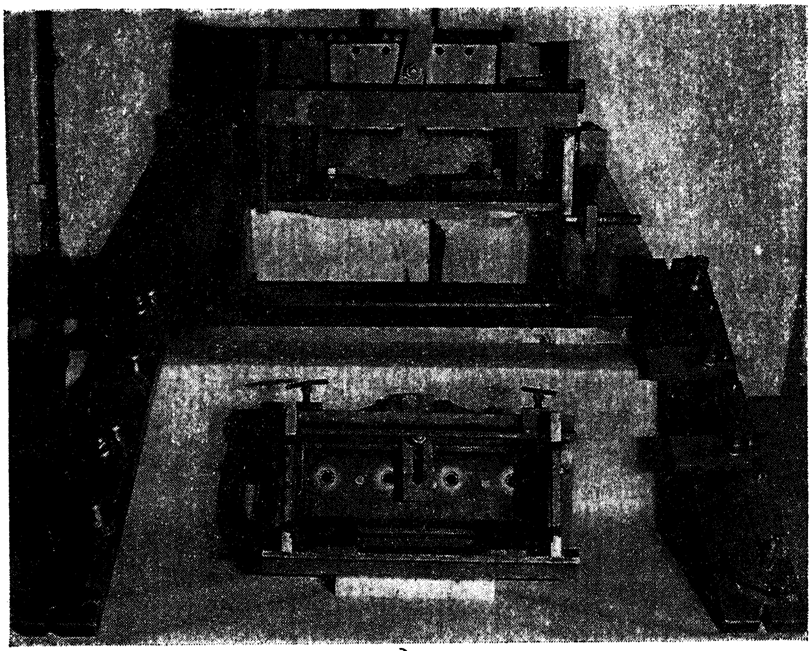


Fig. 1173. Trunnion jig built by arc welding at savings of 25%.

Fig. 1174. Welded steel jig used by a manufacturer of wood-working machines. Assures greater machining tolerances. Welding saved 40% in cost.

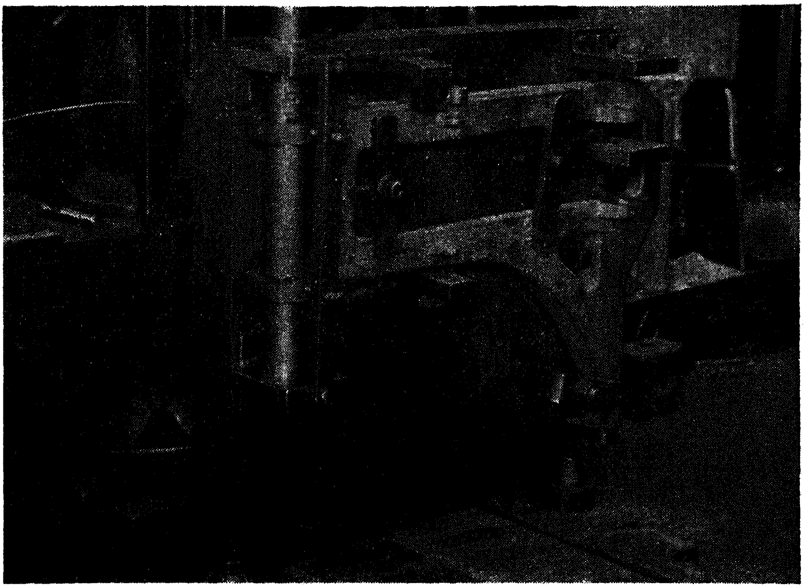


Fig. 1175. Welded steel jig for machining of arbors of wood-working machines. Welding saved 50% in cost.

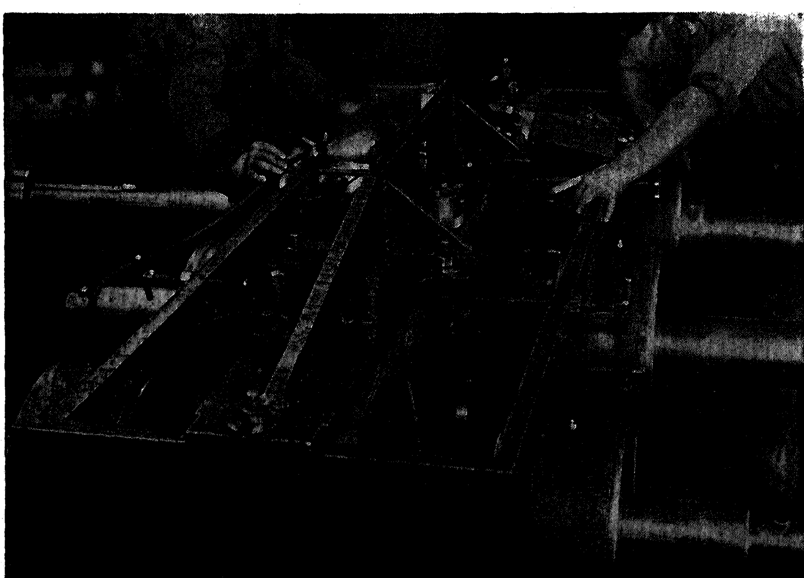


Fig. 1176. Welded steel fixtures used for milling a gear box for a road grader. Welded construction saved 60% in cost.

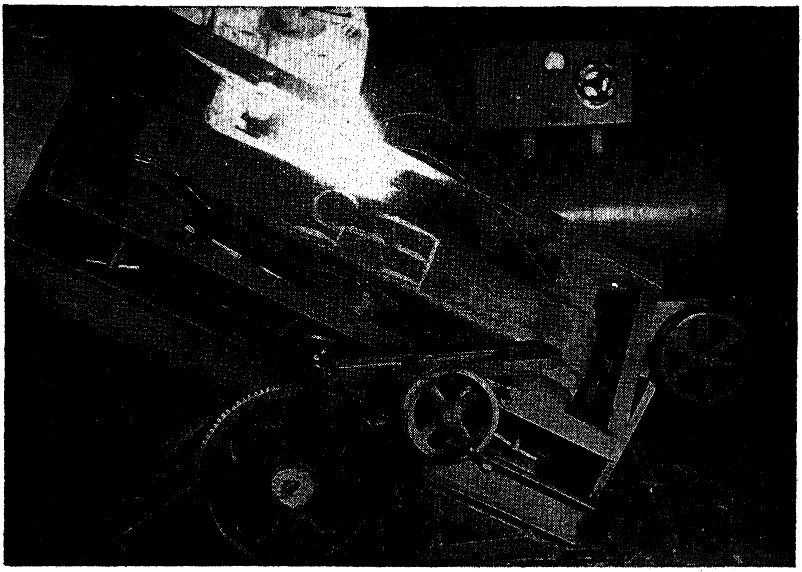


Fig. 1177. Shop-built welded steel positioning jig for welding rocker beam of earth-moving equipment.

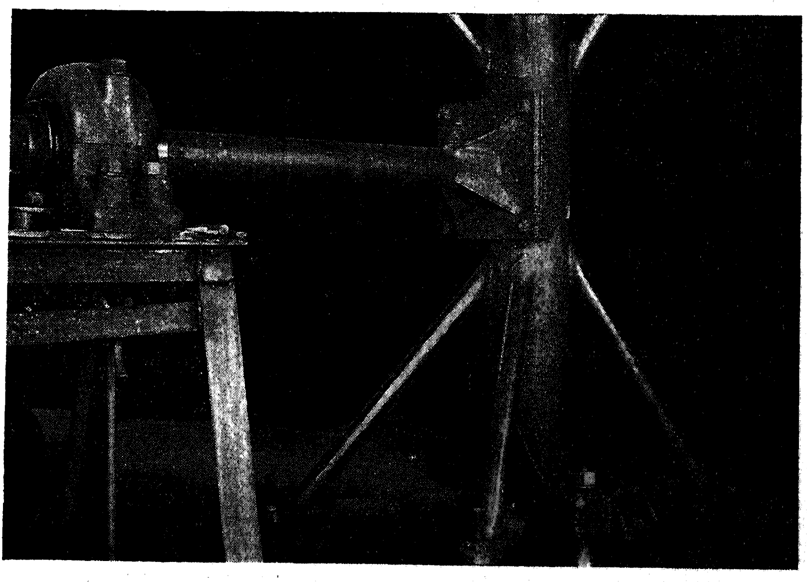


Fig. 1178. Close-up of portion of positioning jig used for welding the bucket of a tractor scraper. This fixture is built from scrap pipe and plate.

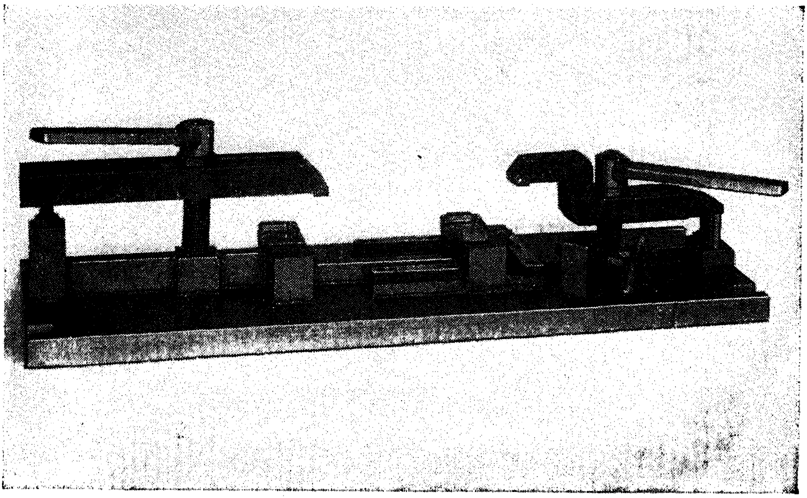


Fig. 1179. Welded steel machining fixture built at a saving of 50%.

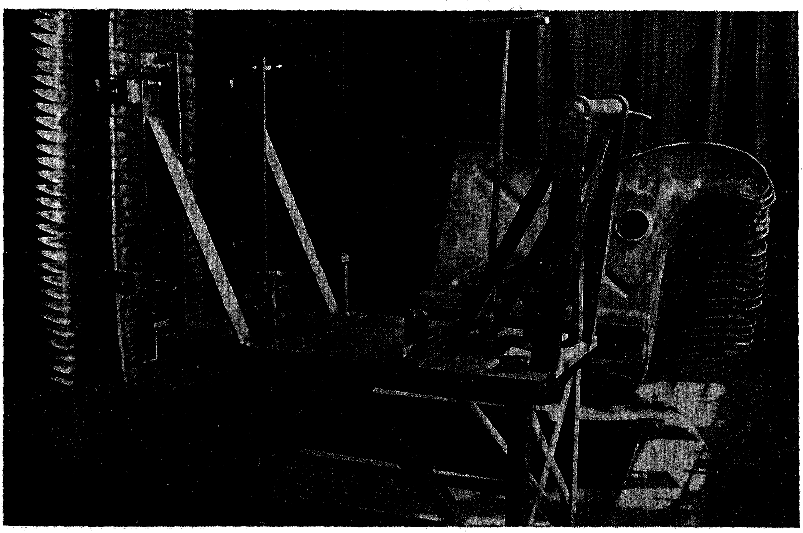


Fig. 1180. Assembly fixture for tack welding parts of pressing machine frame shown in Fig. 468.

Fig. 1181. Fixture for assembling and tack welding parts of small pressing machine frame. Built from angle and flat bar stock by arc welding.

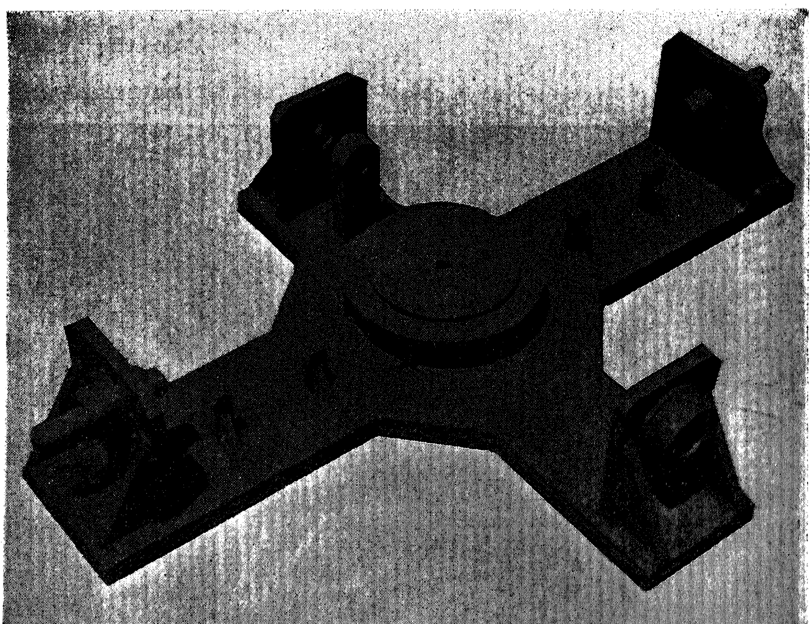


Fig. 1182. Welded steel drill jig for front axle of road-building machine. Weighs 792 lbs. (950 lbs. cast), cost $73.98 ($102.43 cast), built in 36 hrs. (43 hrs. cast).

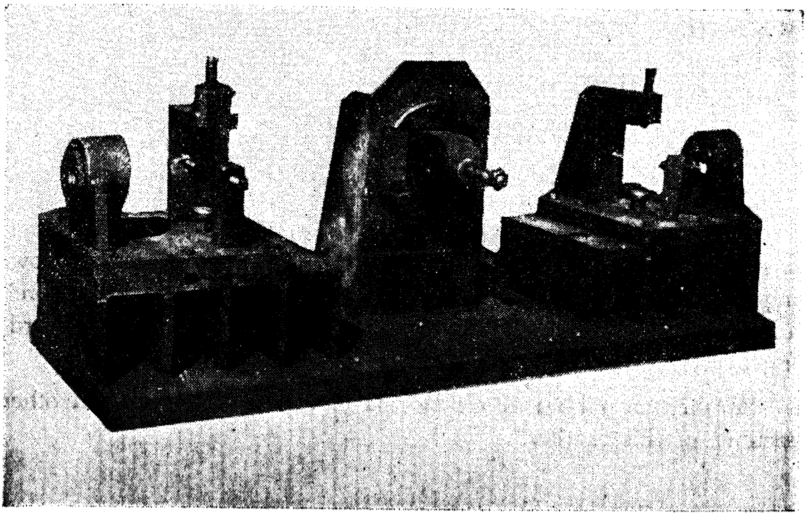


Fig. 1183. Boring fixture for axle, built by arc welding. Weighs 444 lbs. less, costs $63.70 less, built in 32 hours less than cast construction.

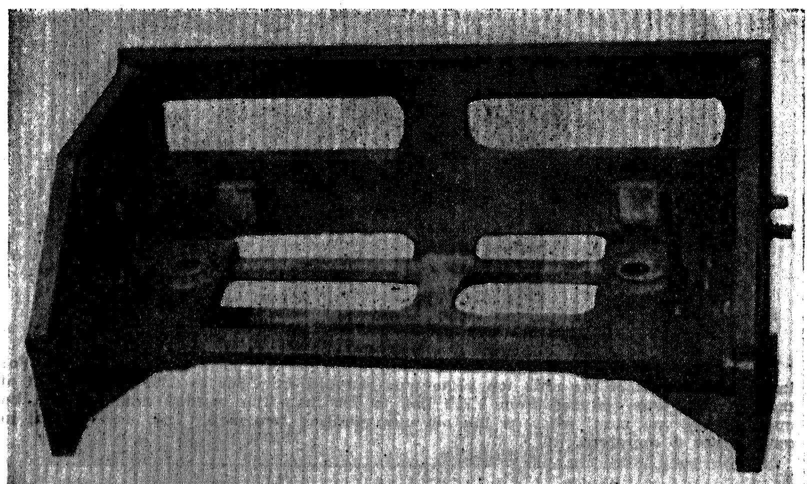


Fig. 1184. Welded drill jig for frame tie. Weighs 362 lbs. (434 lbs. cast), costs $41.59 ($65.12 cast), built in 25 hrs. (39 hrs. cast).

Machine Parts

Changeover from cast or riveted construction to welded design is simple because this can be done one part at a time. On the following pages a wide variety of welded parts are shown, including "before" and "after" case studies as well as many typical parts grouped according to their classification or function.

Finished assemblies of welded machine parts are shown in other sections of this chapter.

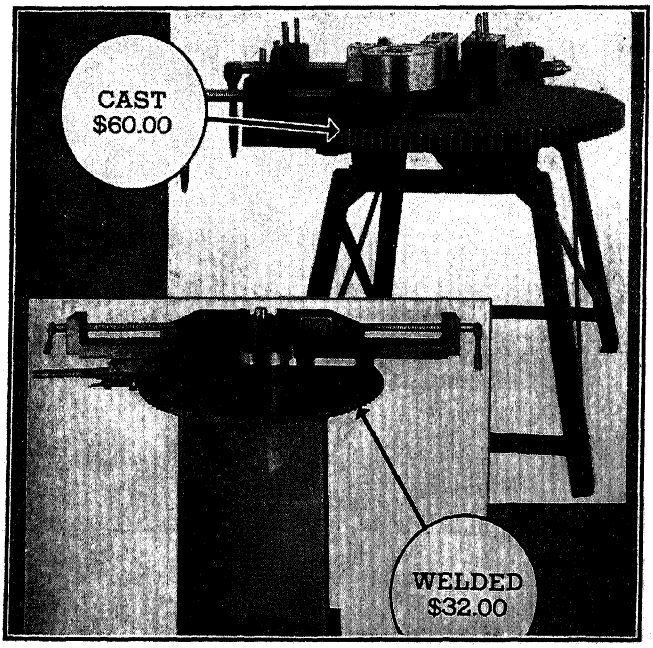


Fig. 1185. Redesign of this bar bending machine cut costs on every part. For instance, the cost of the rack top plate was reduced from $60 to $32. The weight of the machine was reduced from 1,250 lbs. to 736 lbs. The welded machine can be operated by one man, whereas the old one required two men. The improvement in appearance is apparent.

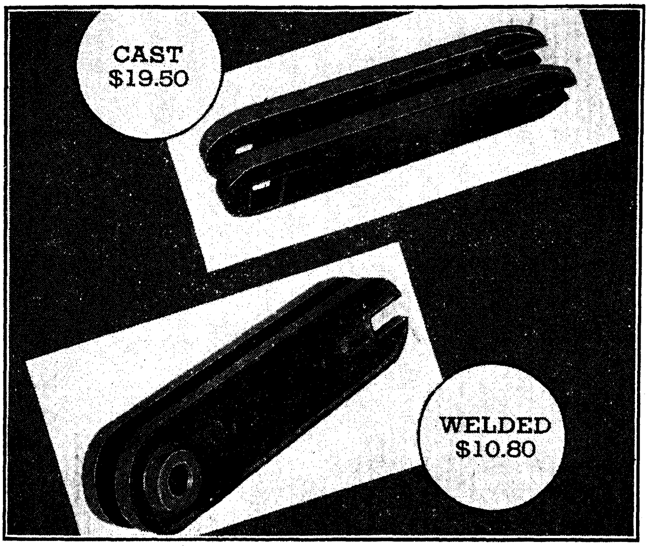


Fig. 1186. Changeover of this sprocket housing from cast iron to welded steel cut its cost from $19.50 to $10.80. Also, the part is now unbreakable.

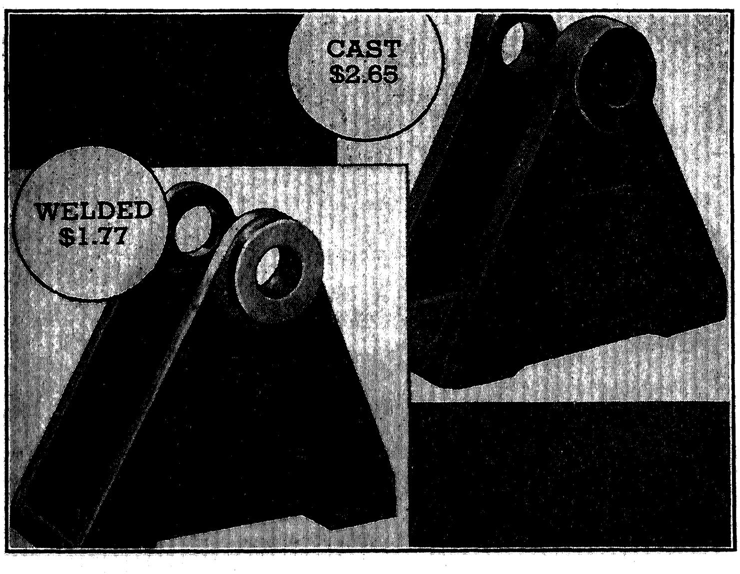


Fig. 1187. This sheave housing for a gas-reducing valve, formerly made from cast iron, cost $2.65 plus pattern charges. Now fabricated from steel, it costs only $1.77 and is unbreakable.

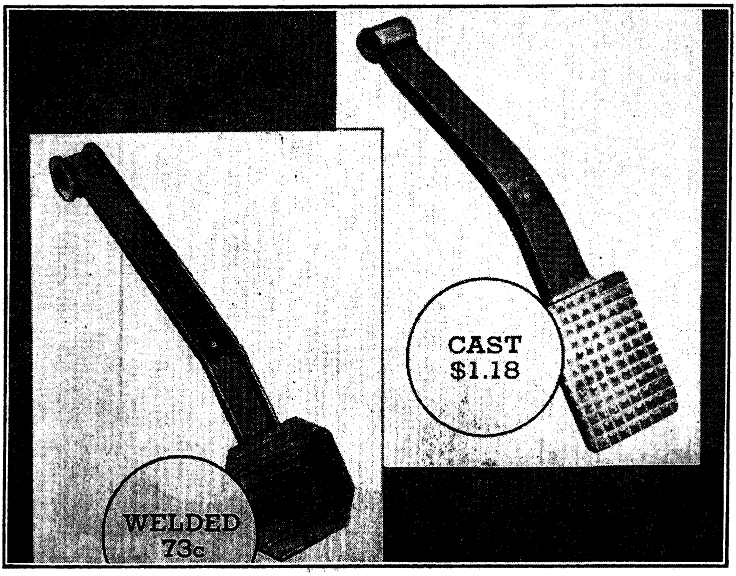


Fig. 1188. Built from a piece of 2-inch channel and checkered floor plate, the unbreakable welded foot treadle costs 73c. The old cast iron treadle, which occasionally broke in service, cost $1.18.

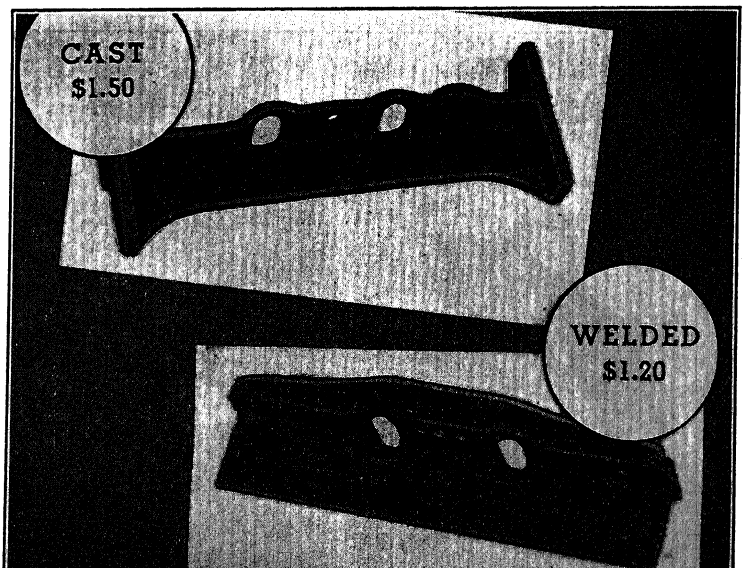


Fig. 1189. The cast iron platform stop for a lift truck was converted to welded steel with a reduction in cost from $1.50 to $1.20. The steel top weighs 35% less and is unbreakable.

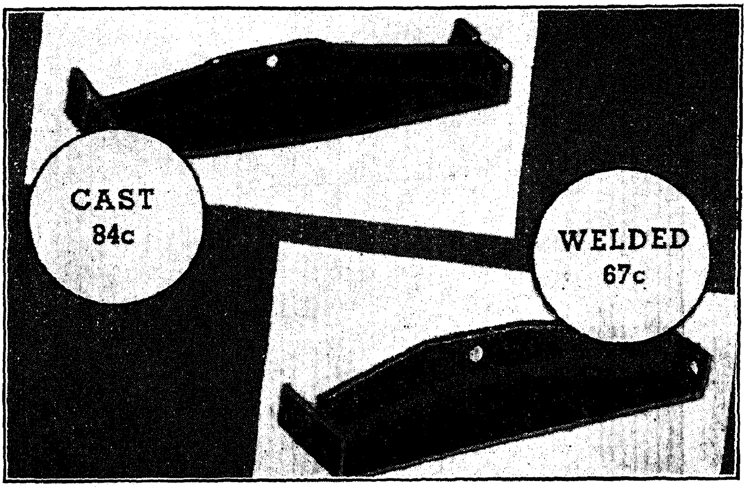


Fig. 1190. The check brace for a lift truck. The cast iron design, which frequently broke, cost 84c. It has been superseded by an unbreakable welded steel brace which costs only 67c.

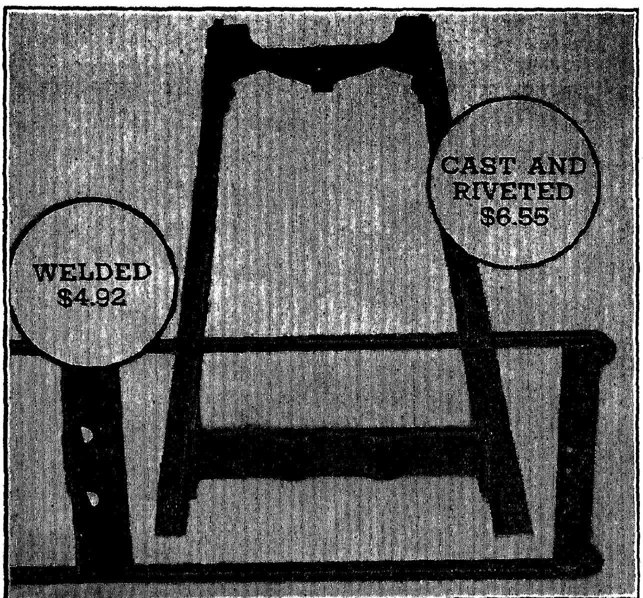


Fig. 1191. The upper frame of a portable lift truck. Changeover from the cast iron, riveted assembly to welded steel construction, saved $1.63 and cut its weight 50%.

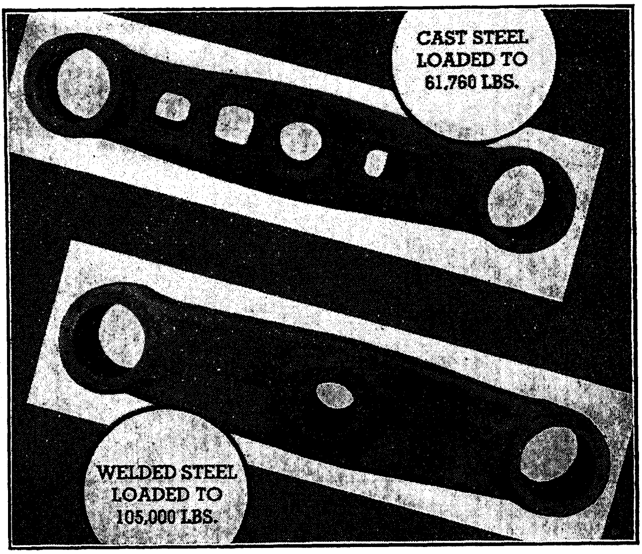


Fig. 1192. Supported at both ends and loaded at the center, the cast steel rocker beam failed at 61,760 lbs. Under the same set-up, the welded steel design withstood a loading up to 105,000 lbs. The weight and cost of each is practically the same.

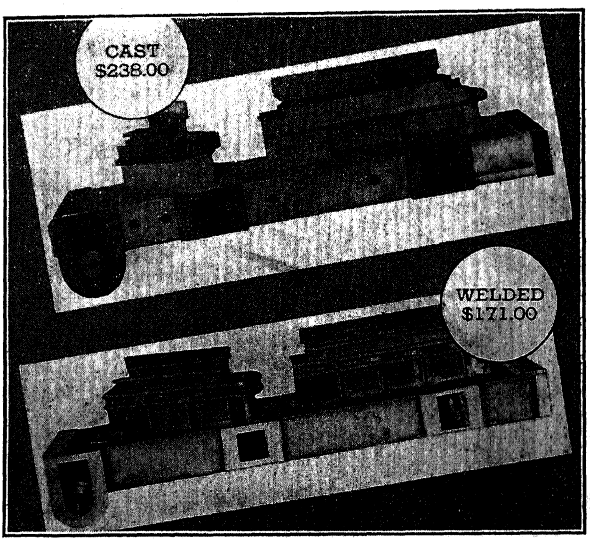


Fig. 1193. The cast iron base cost $238 and weighed 560 lbs. Made of welded steel, it costs $171 and weighs 390 lbs.

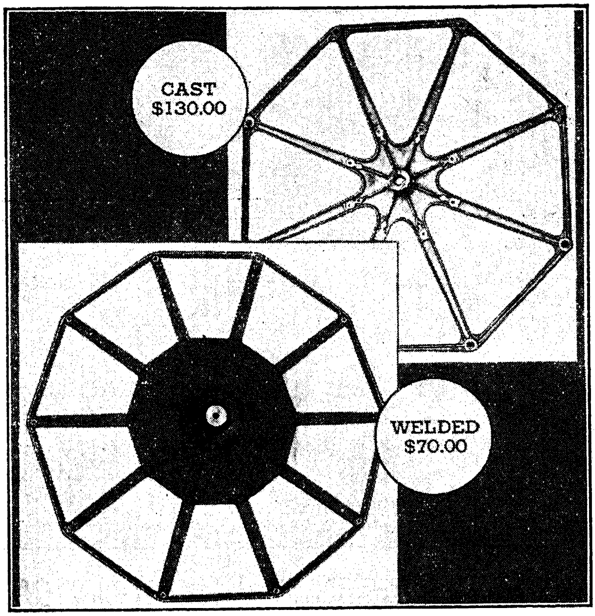


Fig. 1194. An 8-ft. spider for an oven tray conveyor. The cast steel design cost $130, whereas the welded steel costs only $70. Greater accuracy of alignment of bushings is also secured with the welded design, affording smoother performance.

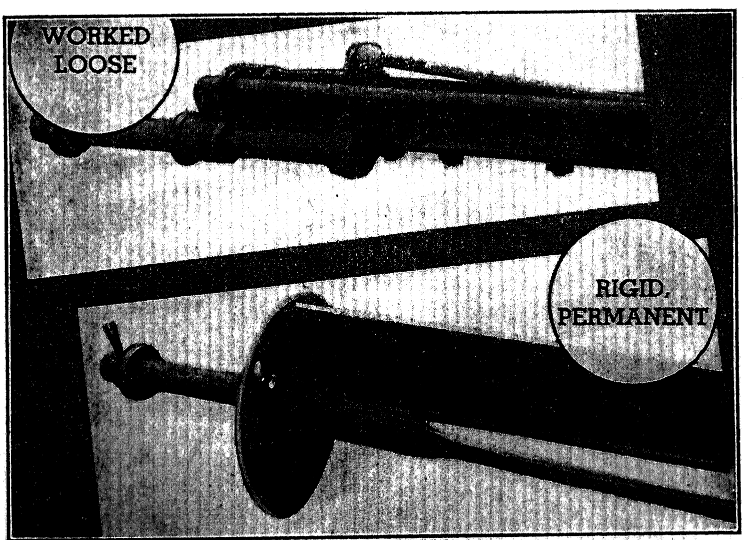


Fig. 1195. The old axle construction of this hay rake consisted of an assembly of castings and a threaded truss rod. The new design is a welded unit of 30% lower cost and permanent construction.

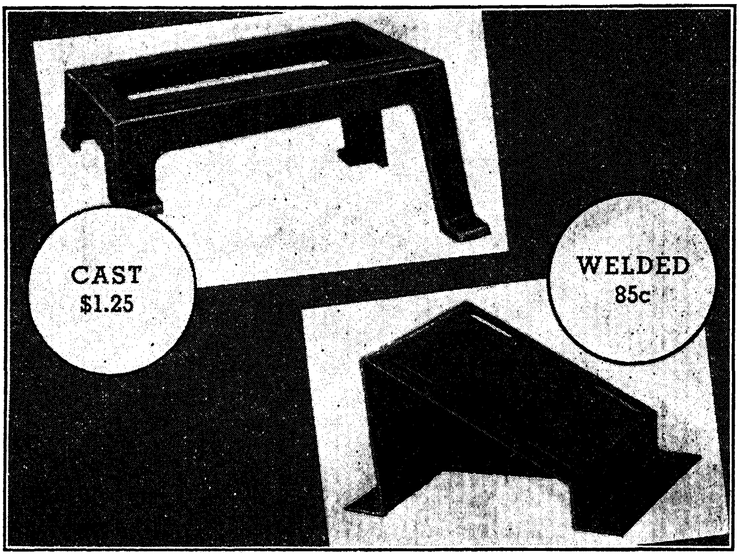


Fig. 1196. A generator base for a grain mill. The cast iron design superseded cost \$1.25; the new welded steel design costs only 85c. Weight reduction was 55%.

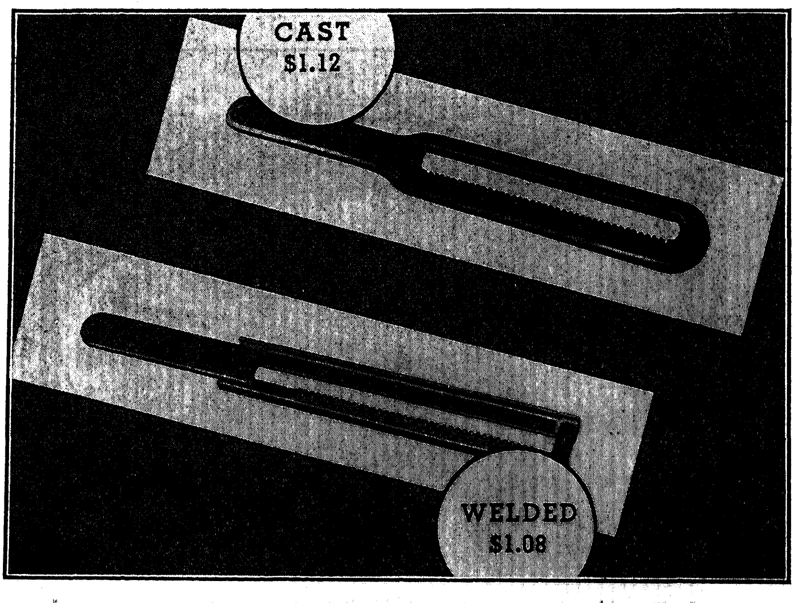


Fig. 1197. This rack, used for adjusting the tilt of a saw table, formerly of cast iron, cost \$1.12, weighed 11 lbs., and was often broken in service. The new welded steel rack costs only \$1.08, weighs 6 lbs., is unbreakable and operates more smoothly

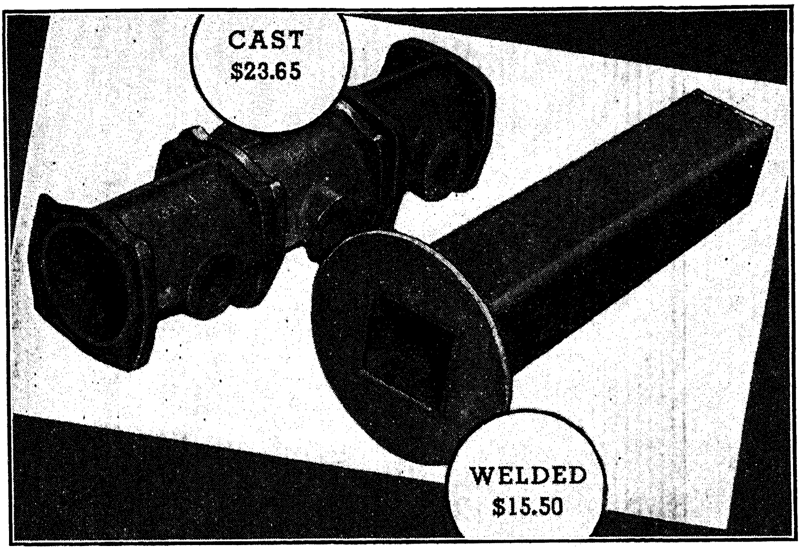


Fig. 1198. Both parts are partially completed headers for a metal washer. The cast iron header consists of a bolted assembly of castings, costing $23.65, complete. The welded steel header is built from two 4 x 4 x 1/4 angles and plate and costs only $15.50, complete. The changeover yielded a savings of $8.15 on every header of this size produced.

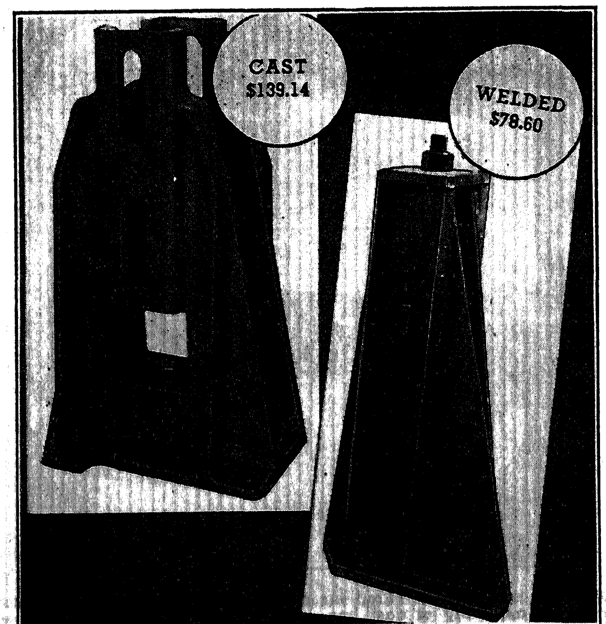


Fig. 1199. The cast steel take-up stand for a crawler shovel was converted to the simple welded steel design shown at a saving of $60.54. Weight was cut 34%.

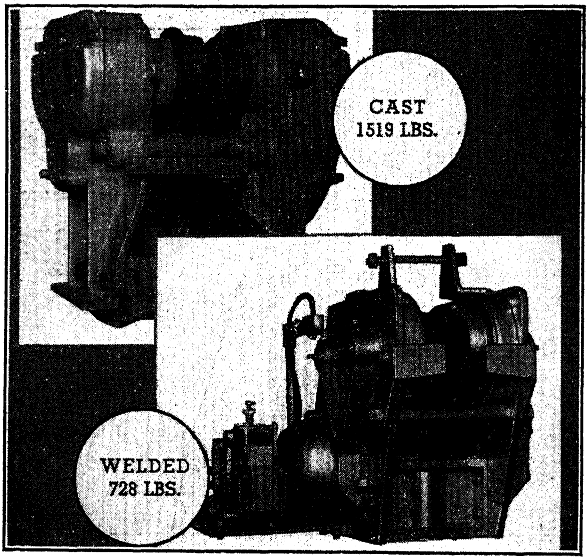


Fig. 1200. This driving trolley for a 10-ton hoist was cut in weight more than half by redesign for welded steel. Savings in cost amounted to $160.44.

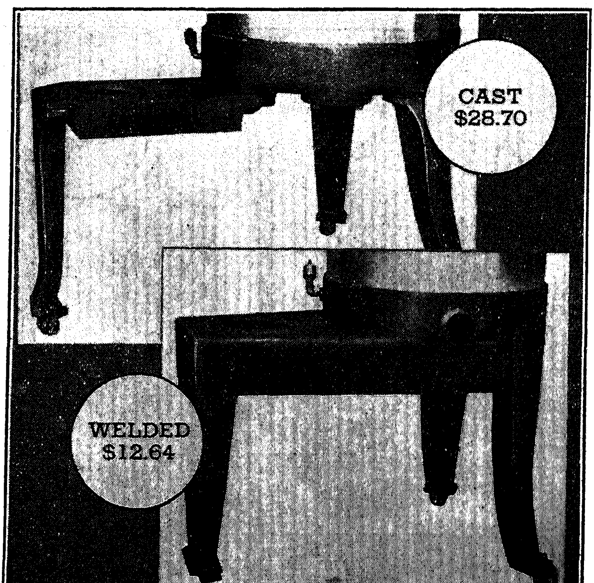


Fig. 1201. This three-legged stand for a potato and vegetable peeler formerly consisted of a bolted assembly of cast iron parts, costing $28.70. The new welded steel design of improved appearance and unbreakable construction costs only $12.64. Moreover, the welded steel model can be supplied in any height desired by the customer; the old design would require separate patterns for every height.

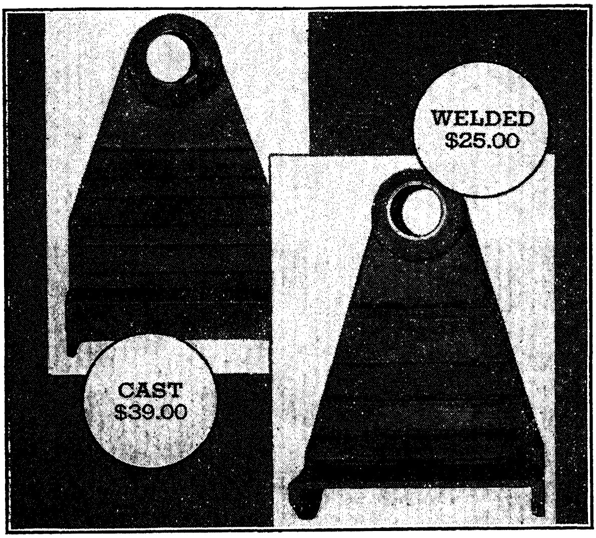


Fig. 1202. A dipper stick yoke for a crawler shovel, changed from a cast steel construction costing $39 to welded steel costing only $25.

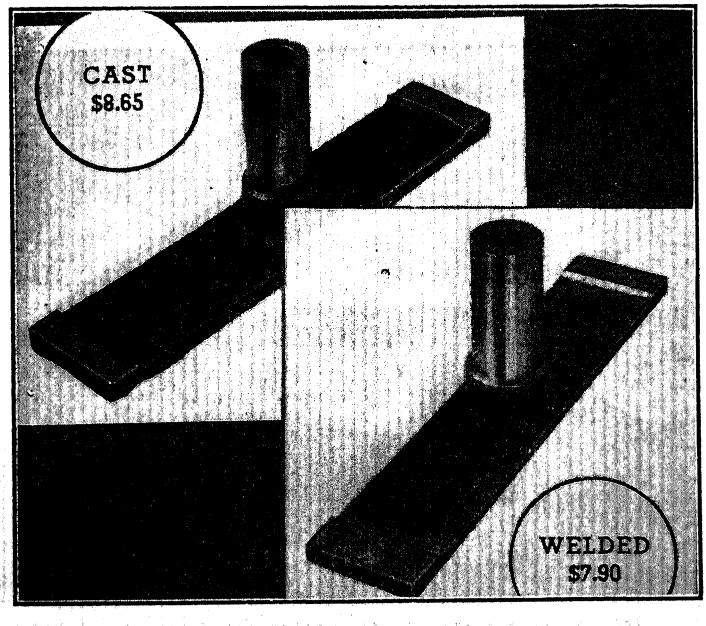


Fig. 1203. This worm gear shaft changeover illustrates the fact that even simple parts can be redesigned at a saving. Here the cost was cut from $8.65 to $7.90.

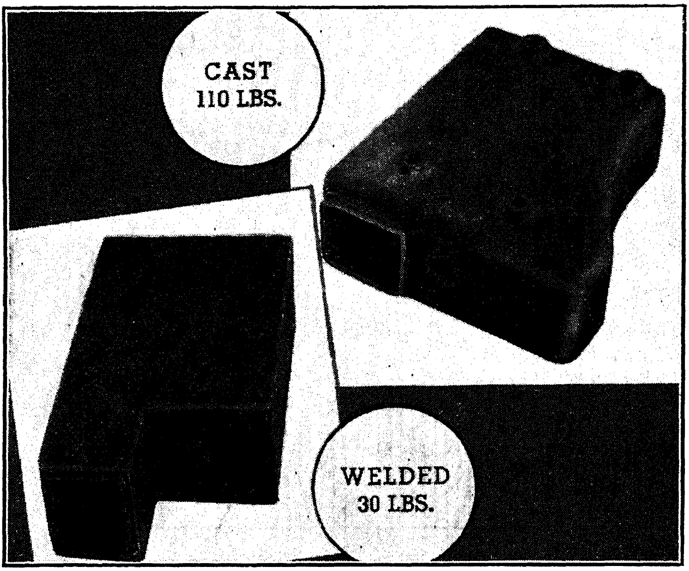


Fig. 1204. Redesign of this sand box for a mining locomotive cut weight almost 73%. This changeover is typical of many of this equipment wherein reductions in dead weight mean lower haulage costs. The welded design costs 60% less than the cast iron.

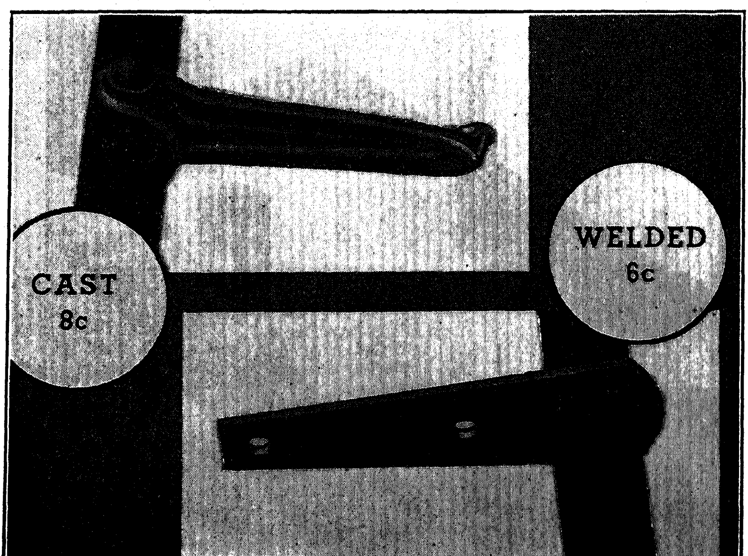


Fig. 1205. The old cast iron lever arm for a spring tooth harrow was bolted to the post as shown at a total cost of 8c. The new unbreakable steel lever, welded permanently to the post, costs only 6c.

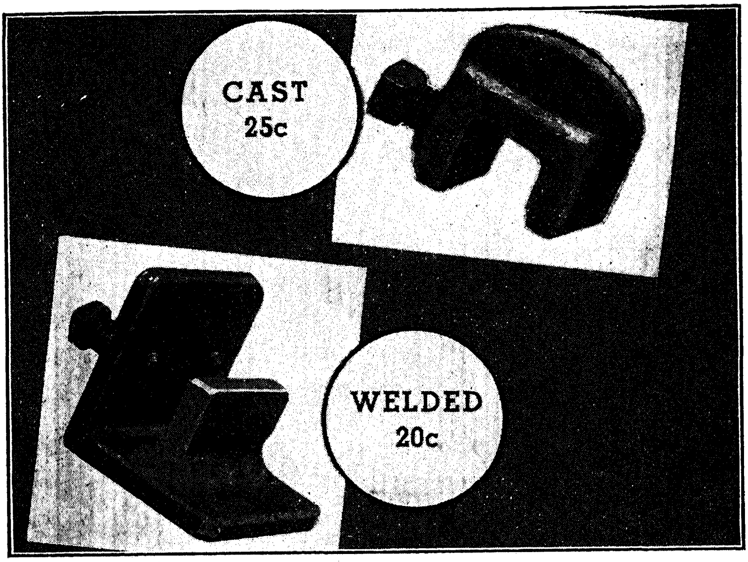


Fig. 1206. This degree gauge for a bar bending machine formerly required separate patterns for every size machine. It cost 25c. The welded design, costing 20c, can be made to suit any size machine without additional cost or production delay.

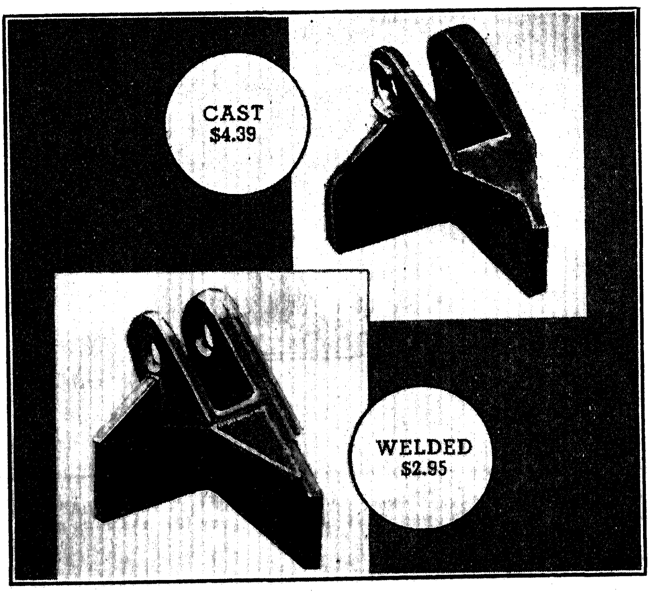


Fig. 1207. Built of cast steel, this bracket for a shovel bucket cost $4.39. It was changed to welded steel construction at a saving of $1.44 or 32%.

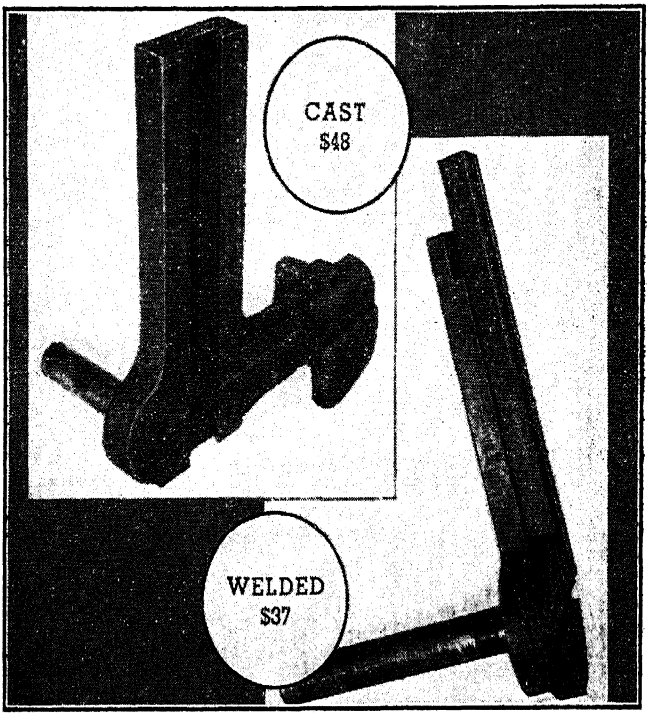


Fig. 1208. Bending arm and ratchet control for a bar bending machine. The cast iron part cost $48, weighs 225 lbs., and occasionally broke. The welded steel design costs $37, weighs 185 lbs., and is unbreakable.

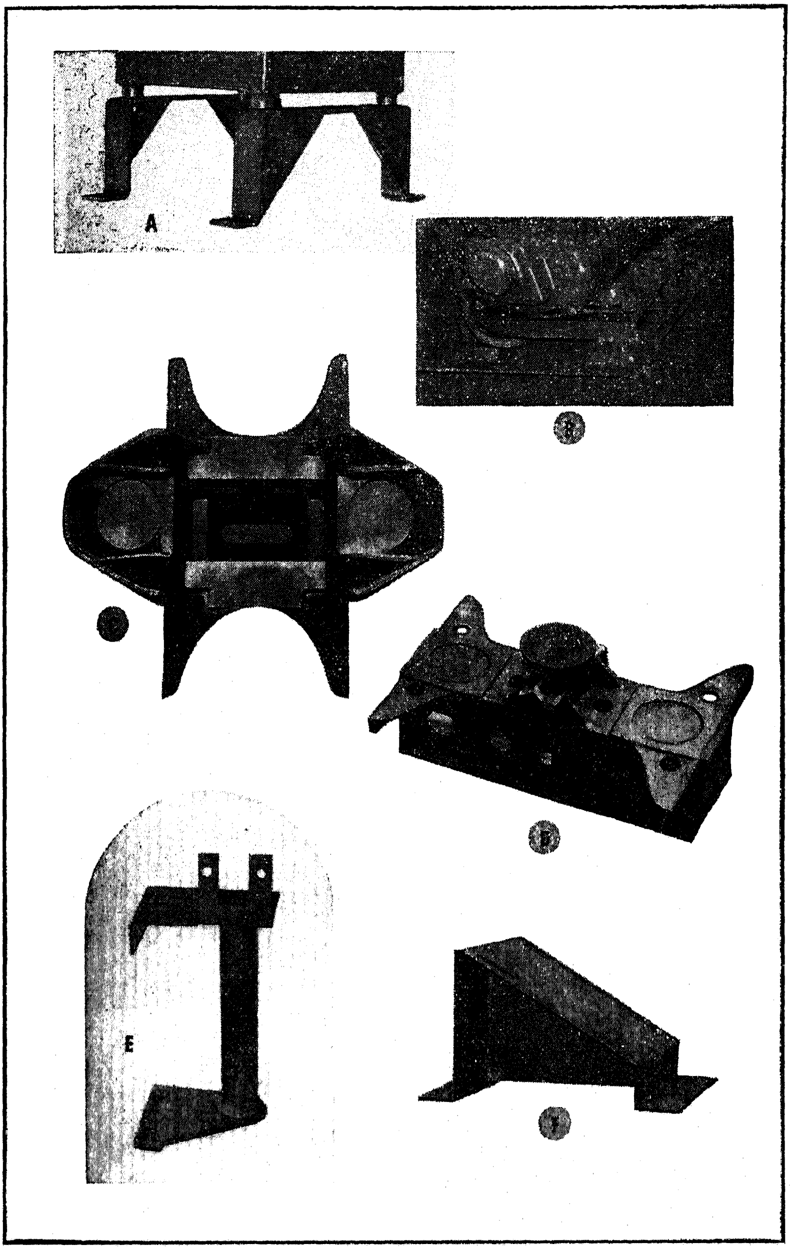


Fig. 1209. BASES—(A) Foot construction for sump tank. (B) Sliding base for motor. (C) Bogie frame stretcher. (D) Pony truck. (E) Valve controller stand. (F) Generator base for grain mill.

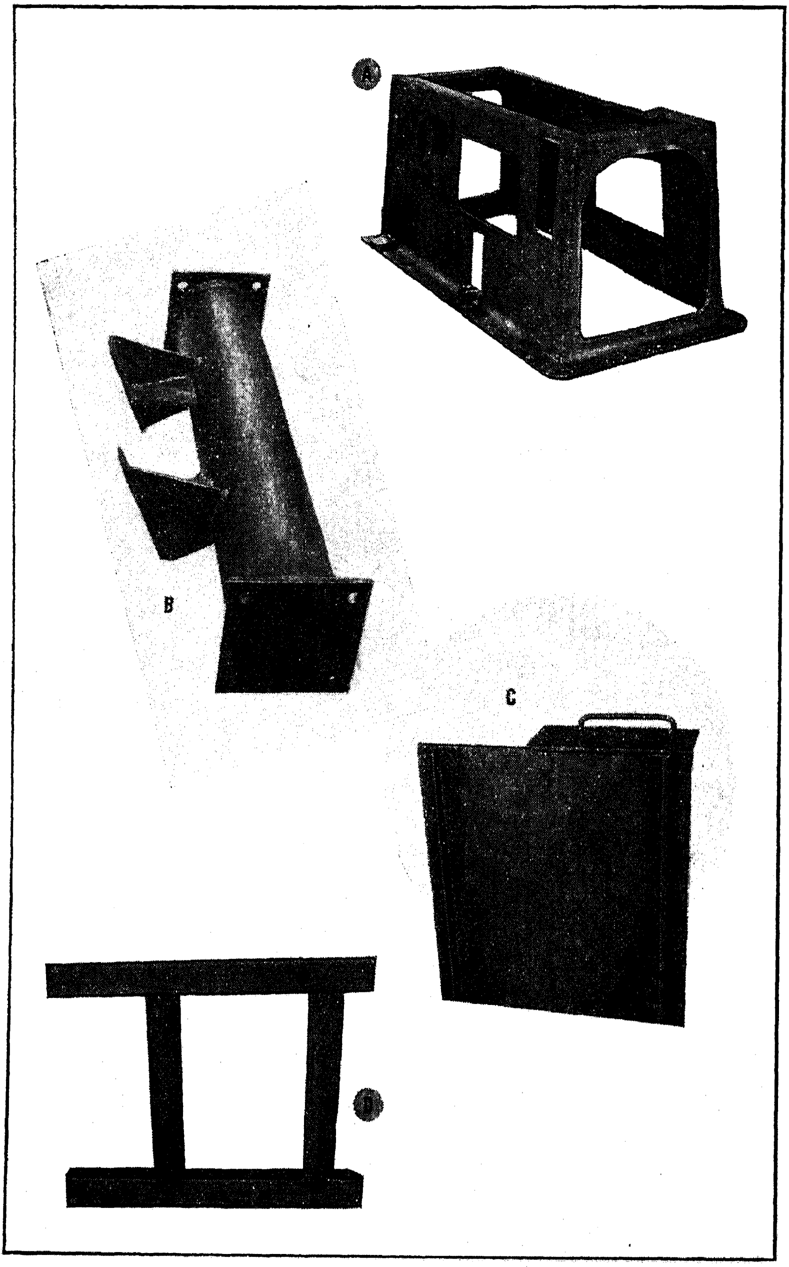


Fig. 1210. BASES—(A) Sub-base for machine tool. (B) Tandem drive gearbox support. (C) Roller table for band saw. (D) Engine base for small machine.

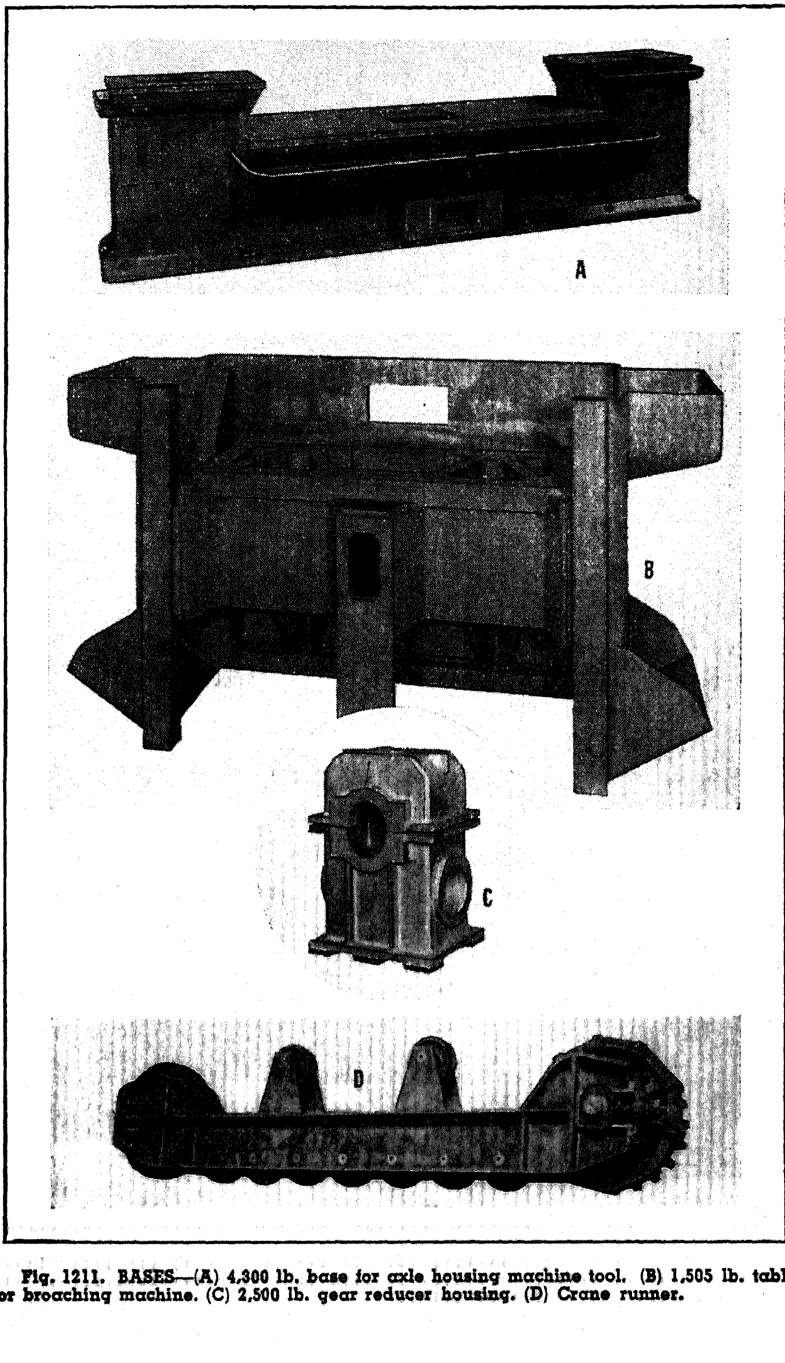


Fig. 1211. BASES—(A) 4,300 lb. base for axle housing machine tool. (B) 1,505 lb. table for broaching machine. (C) 2,500 lb. gear reducer housing. (D) Crane runner.

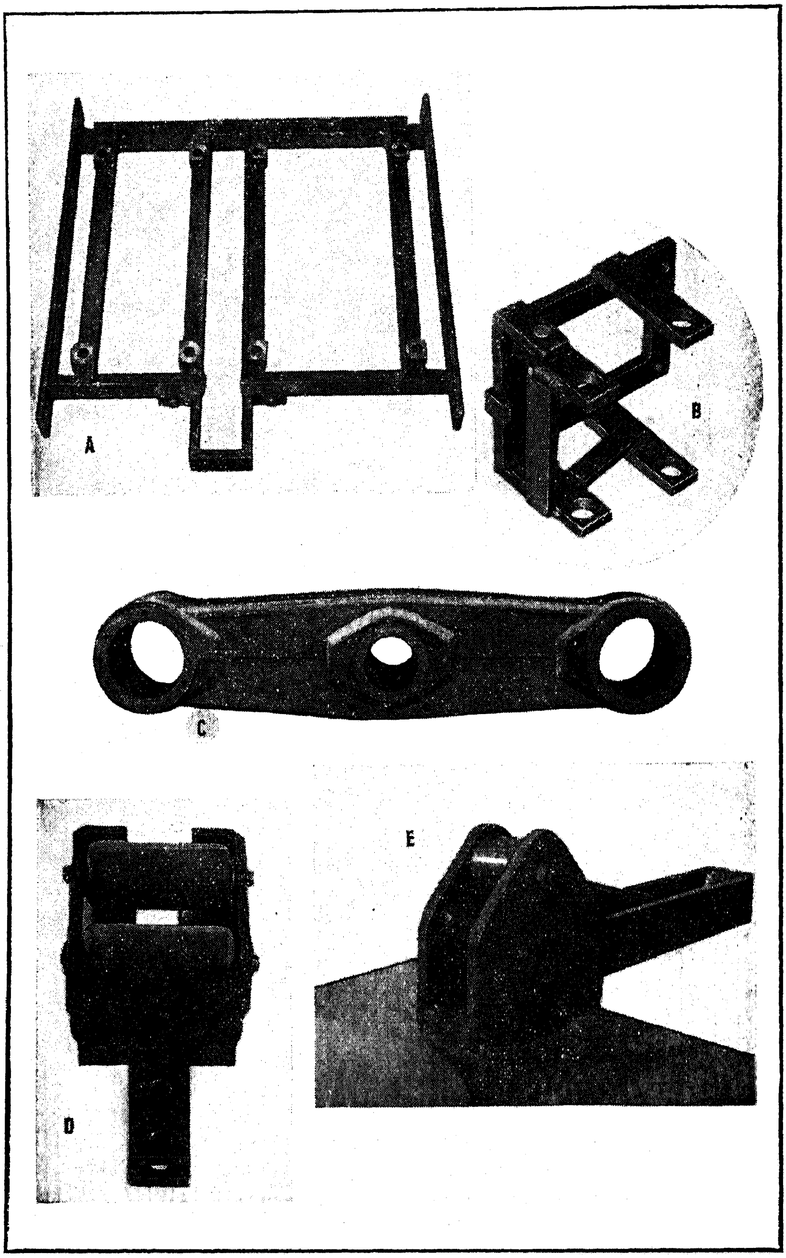


Fig. 1212. FRAMES—(A) Roller table frame for dry ice saw. (B) Idler pulley frame. (C) Rocker beam for earth-mover wheels. (D) Cable guide for mining machine. (E) Pressure block housing for bar bending machine.

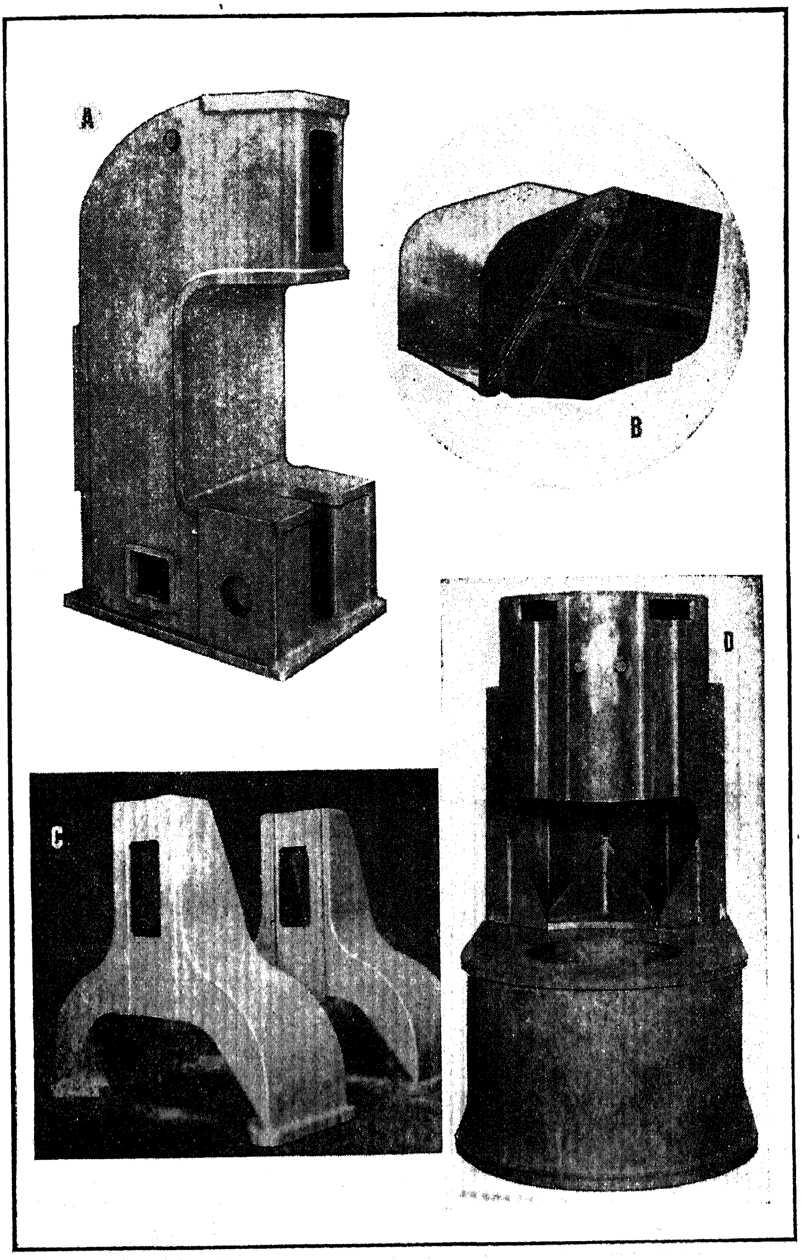


Fig. 1213. FRAMES—(A) 4,600-lb. frame for drilling machine. (B) High tensile steel pan for earth scraper. (C) 2,200-lb. columns for boring machine. (D) 2,500-lb. hydraulic press frame.

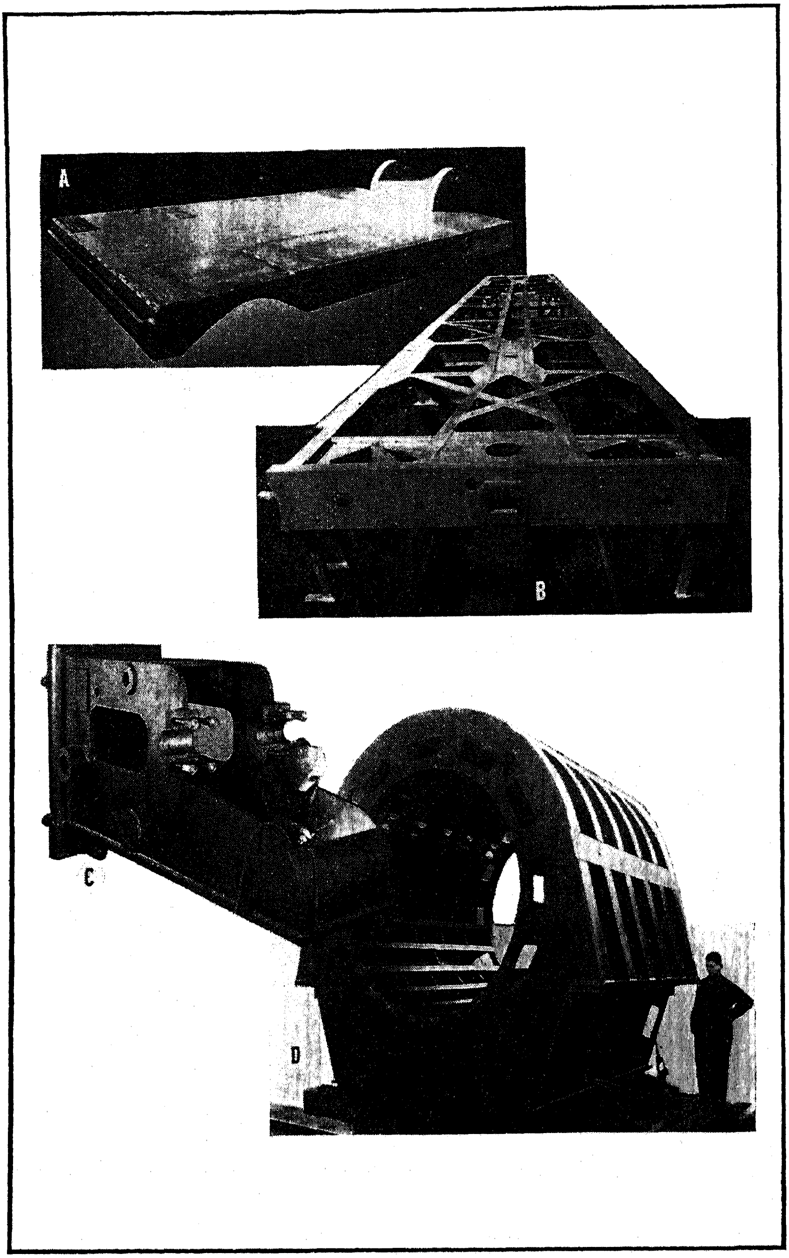


Fig. 1214. FRAMES—(A) Frame for heavy duty trailer. (B) Underframe for railroad passenger car. (C) 5-ton press housing. (D) 25-ton turbo-generator frame.

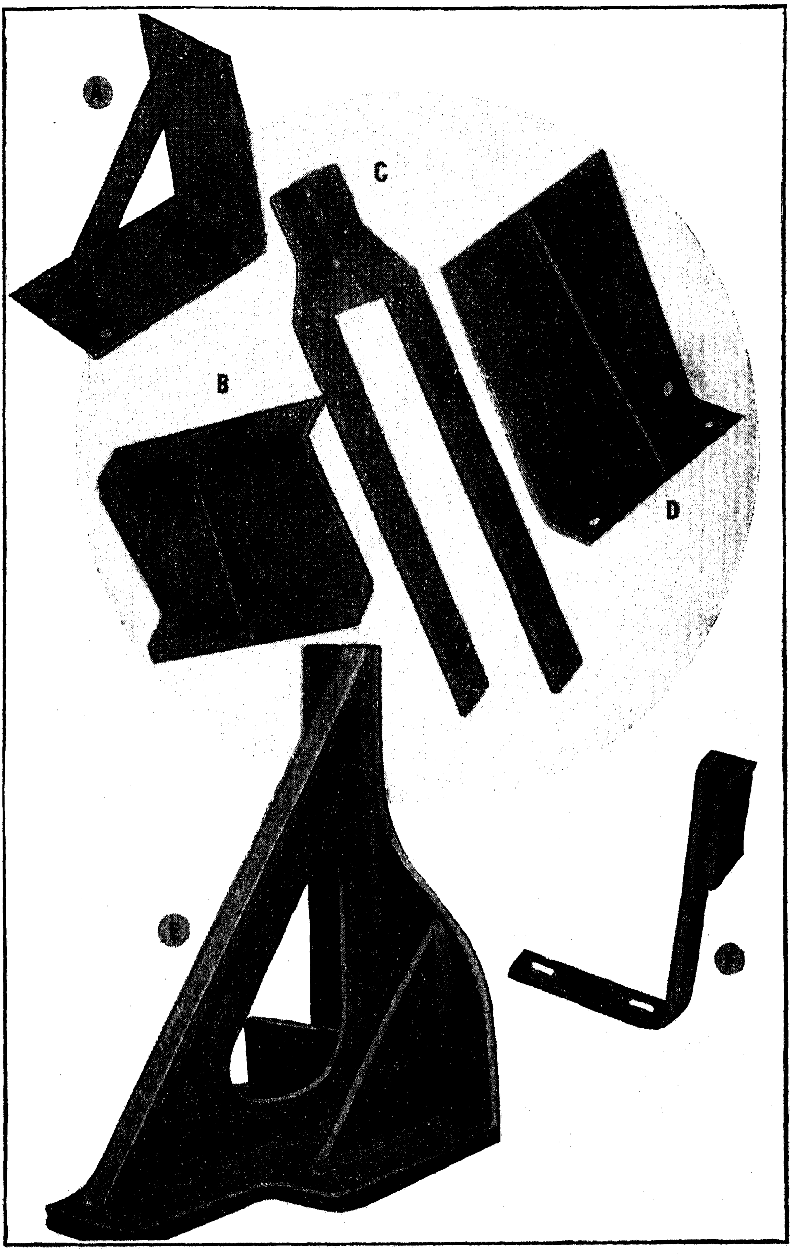


Fig. 1215. BRACKETS—(A) Engine bracket for crawler shovel. (B) Diesel engine radiator spacer bracket. (C) Brake bracket for crawler shovel. (D) Chain casting support. (E) Steam locomotive bugger beam bracket. (F) Woodworker splitter knife holder.

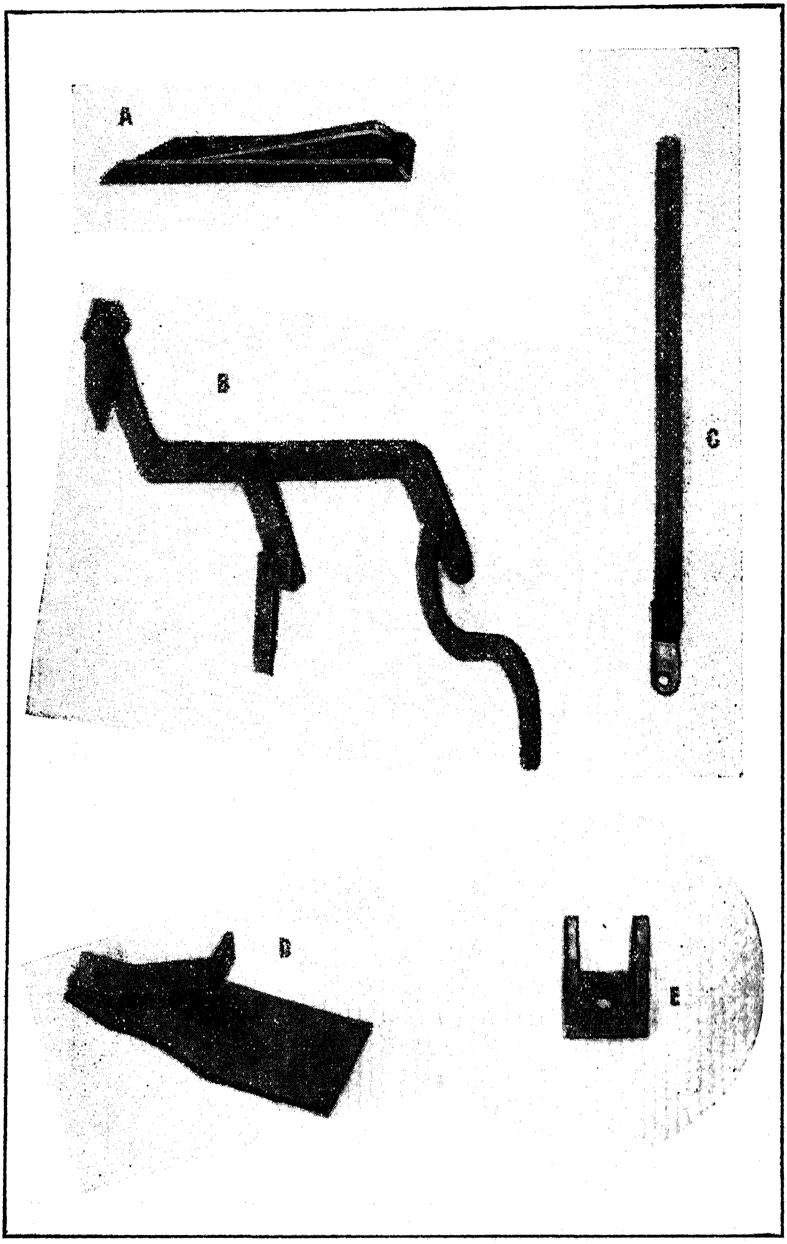


Fig. 1216. BRACKETS—(A) Cross-cut gauge for woodworker. (B) Saw guard bracket. (C) Saw clamp shaft. (D) Grader bracket for harvester. (E) Saw clamp bracket.

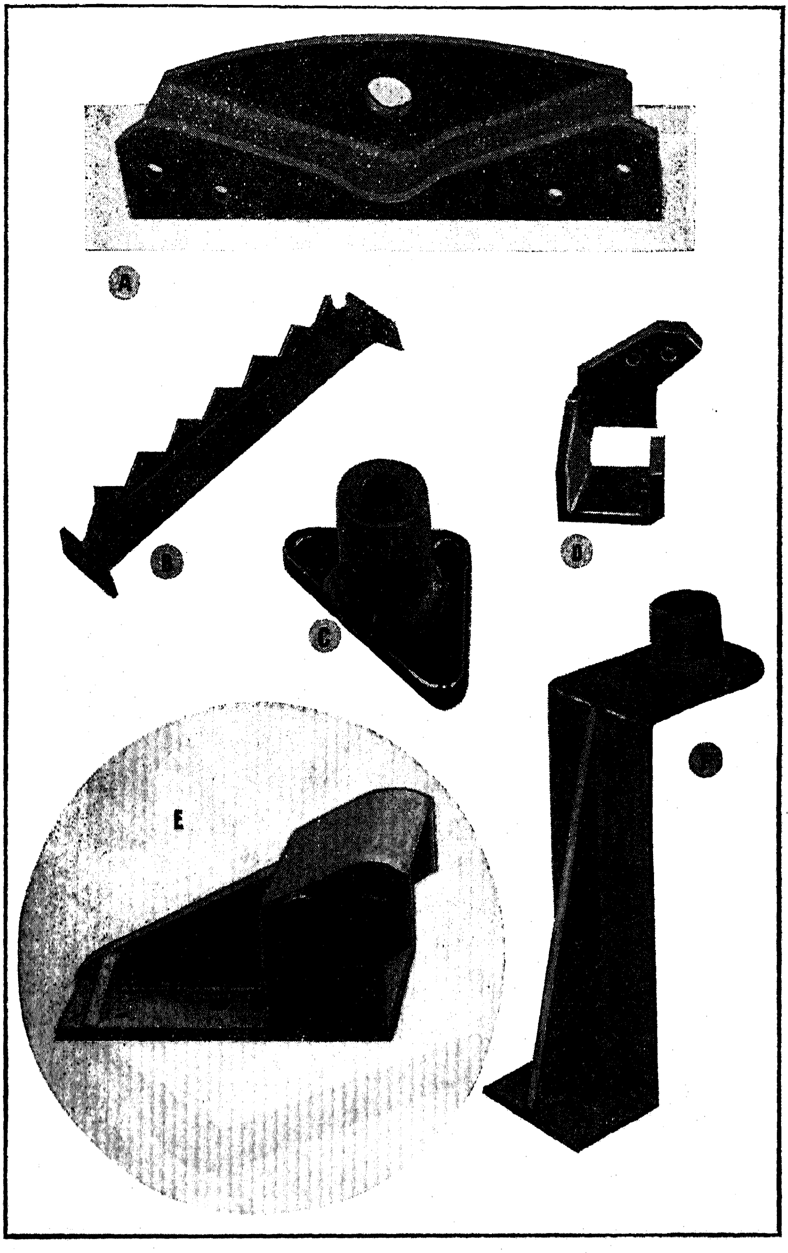


Fig. 1217. BRACKETS—(A) Adaptor for locomotive bumper. (B) Flight for conveyor. (C) Brake hanger support. (D) Bracket for clutch hoist. (E) Bracket for paper machine. (F) Air cleaner support bracket.

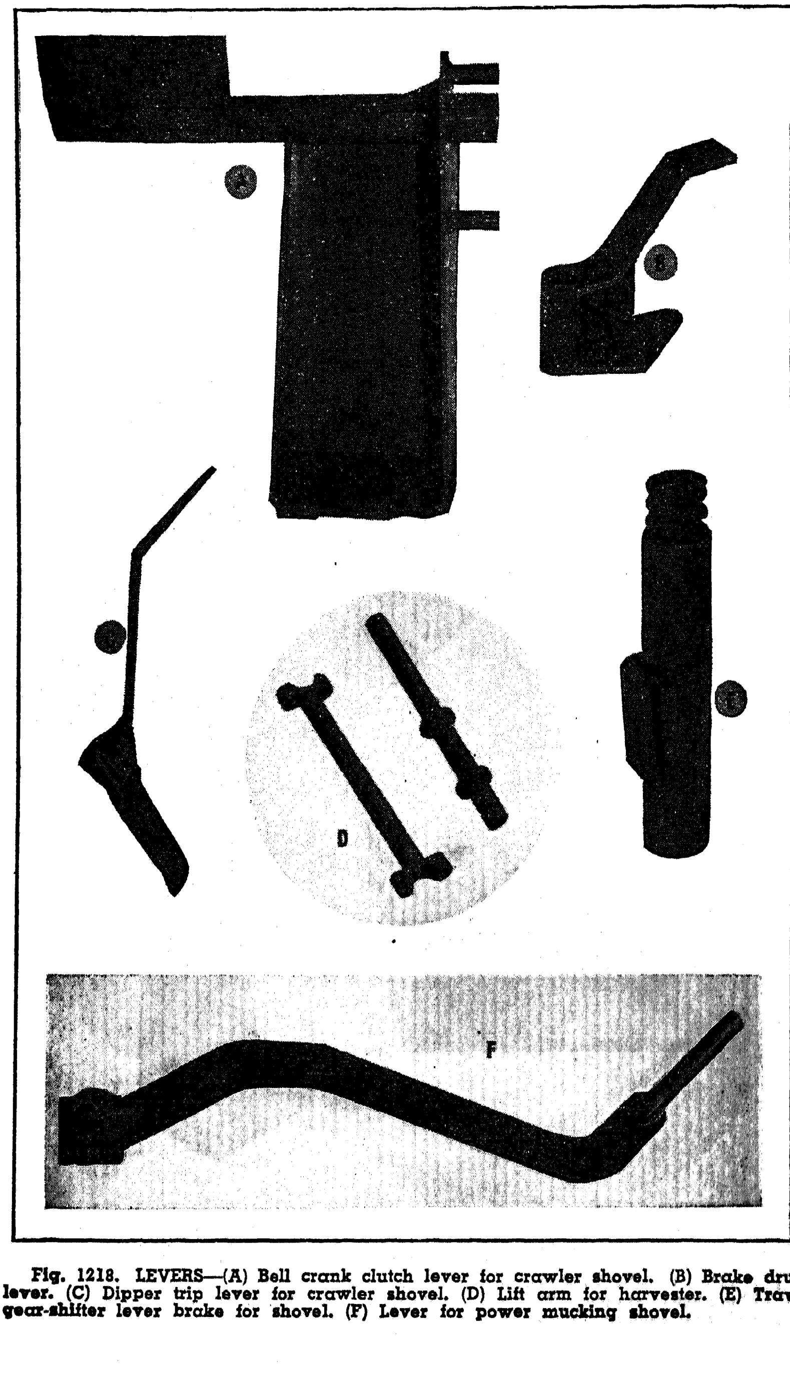


Fig. 1218. LEVERS—(A) Bell crank clutch lever for crawler shovel. (B) Brake drum lever. (C) Dipper trip lever for crawler shovel. (D) Lift arm for harvester. (E) Travel gear-shifter lever brake for shovel. (F) Lever for power mucking shovel.

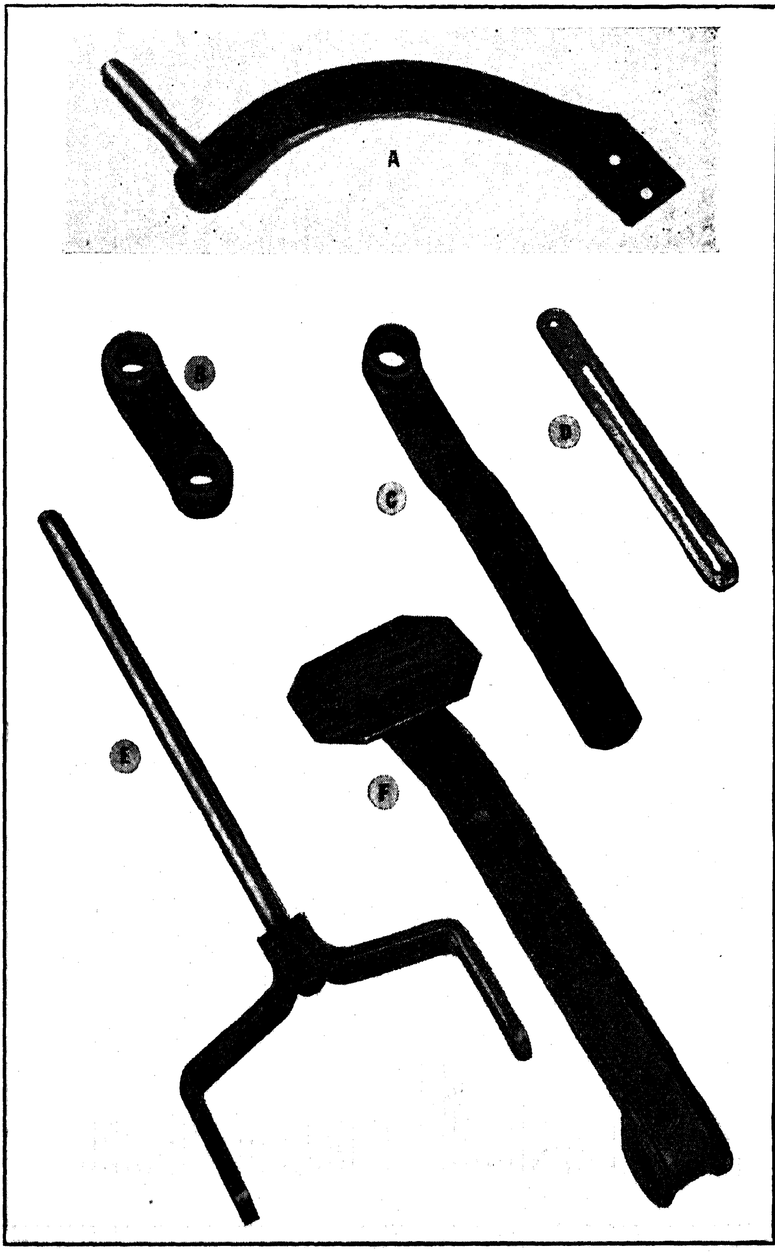


Fig. 1219. LEVERS—(A) Woodworker splitter knife. (B) Yoke lever for woodworker. (C) Hand lever. (D) Table link. (E) Yoke fork. (F) Foot treadle.

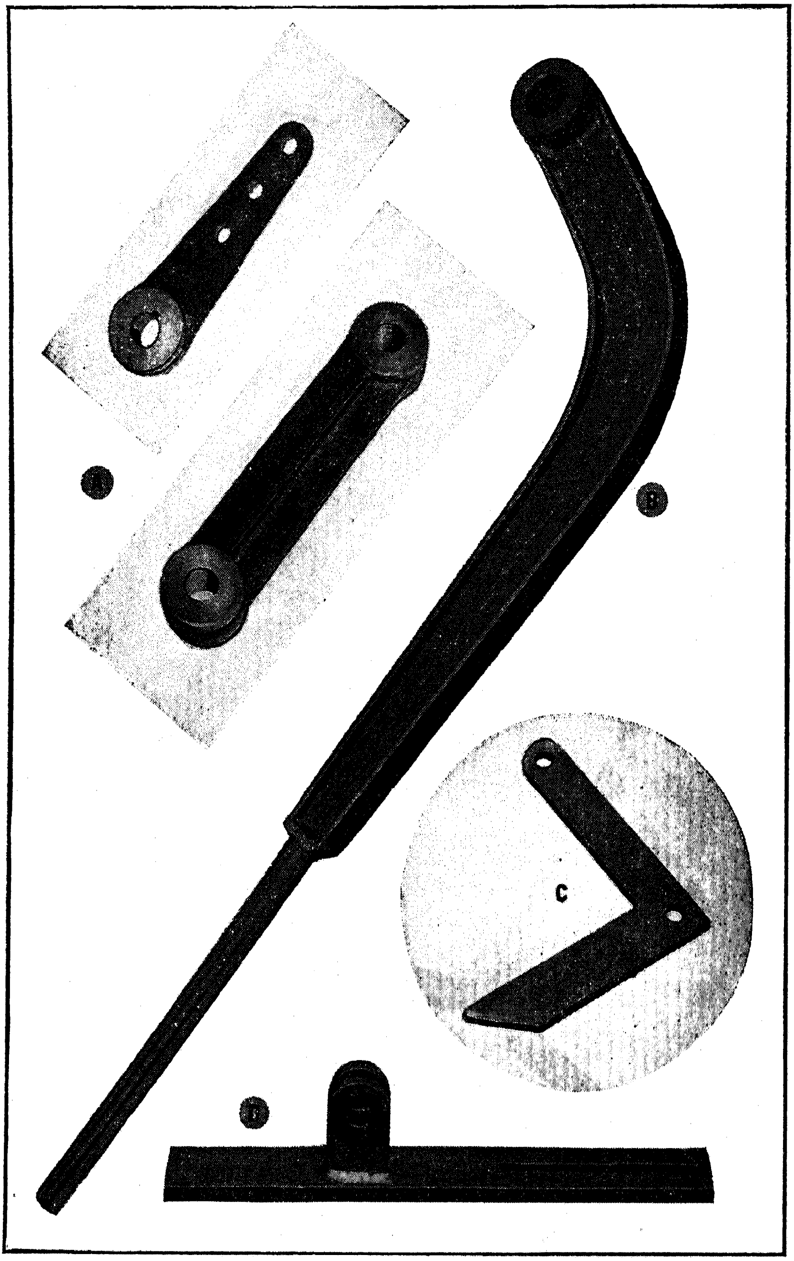


Fig. 1220. LEVERS—(A) Levers for industrial furnace. (B) Handle for paper cutting machine. (C), (D) Levers for wire reel.

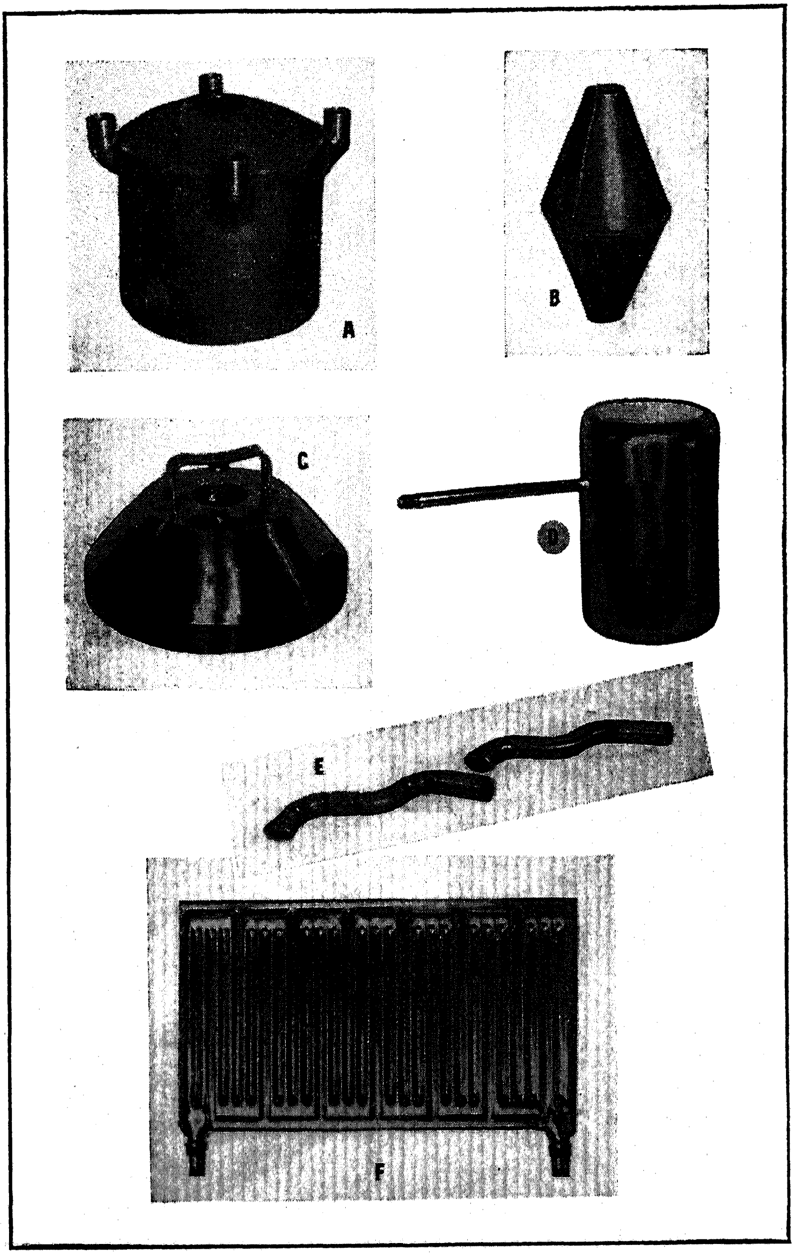


Fig. 1221. CONTAINERS—(A) Vacuum pan bottom section. (B) Exhaust steam condenser. (C) Stainless steel milk tank float. (D) Stainless steel mercoid switch float. (E) Stainless steel ammonia inlet for milk cooler. (F) Stainless steel milk cooler refrigerant section.

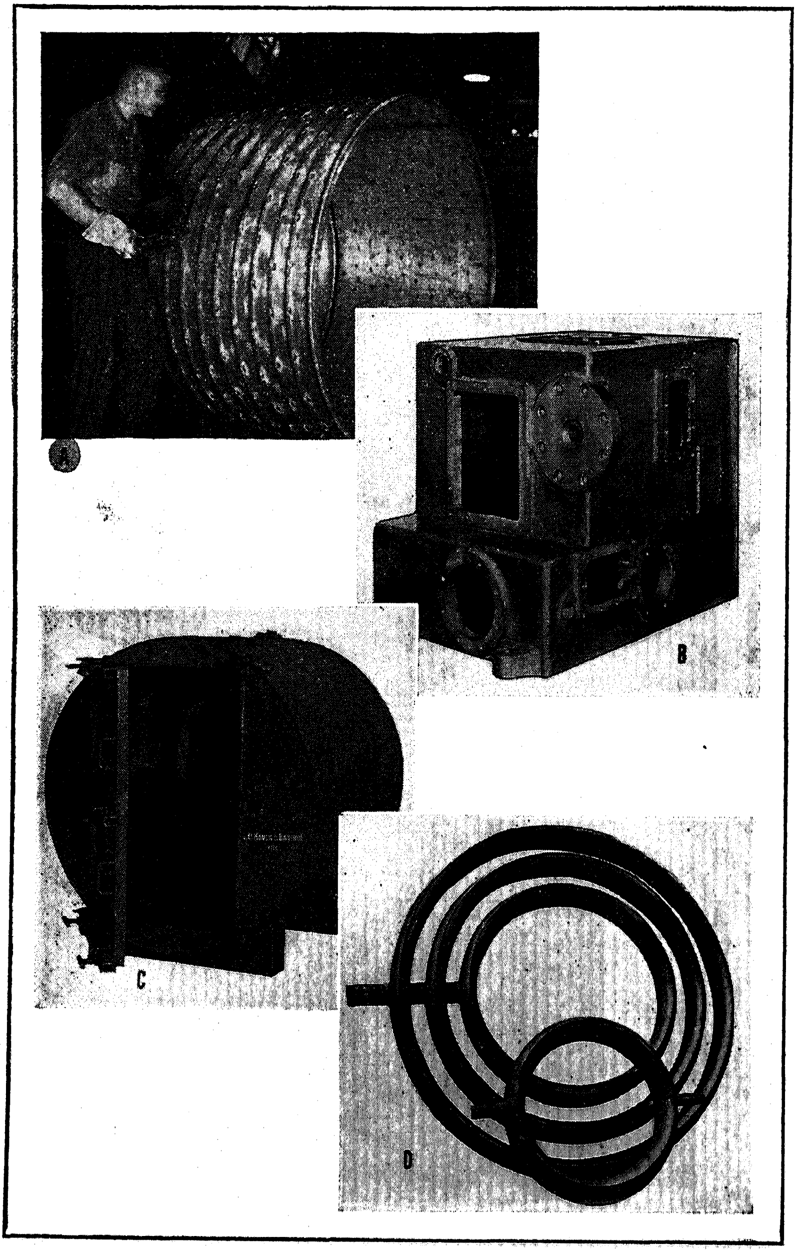


Fig. 1222. CONTAINERS—(A) Inside tank for pasteurizer. (B) 400-lb. tank for process machine. (C) Steam-treating chamber for processing of silks. (D) Cooling coils for milk pasteurizers.

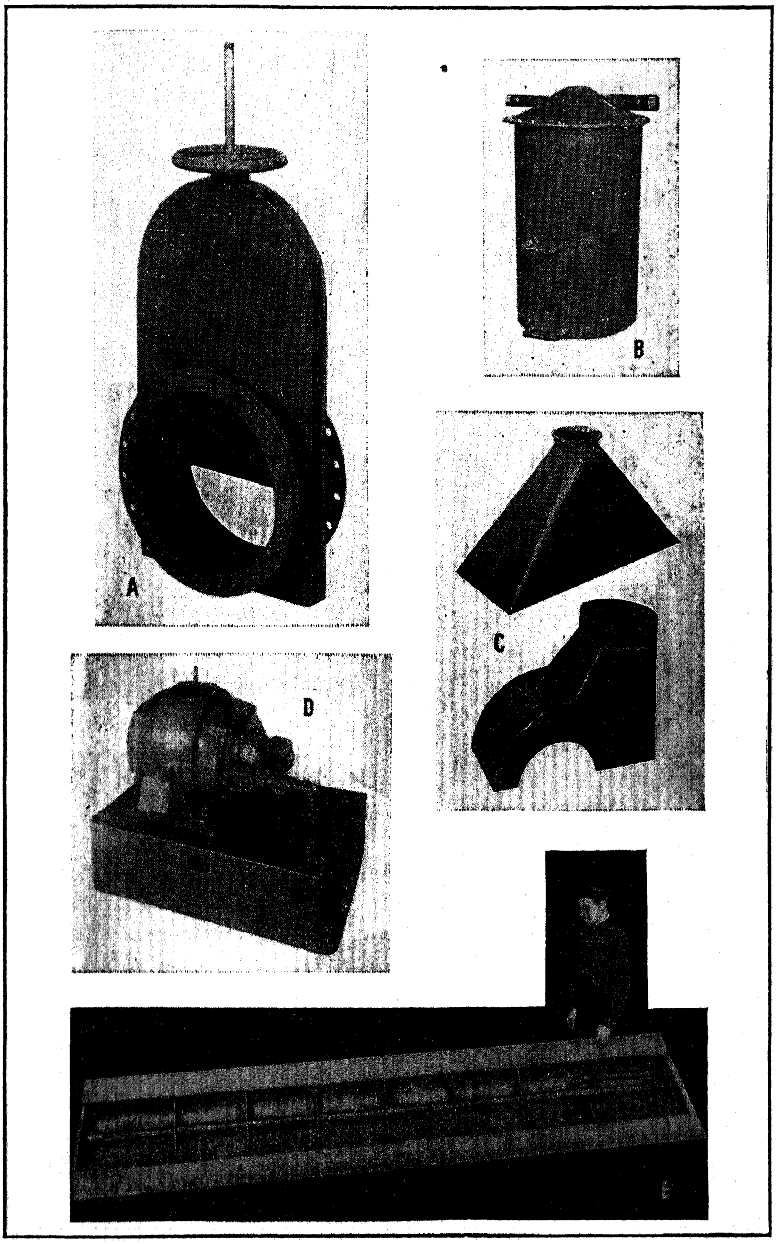


Fig. 1223. CONTAINERS—(A) 30-inch blast gate for gas producer. (B) Vacuum pan condenser. (C) Fan dischargers for grain mill. (D) Combination base and oil reservoir. (E) 1,300-lb. Diesel engine oil pan.

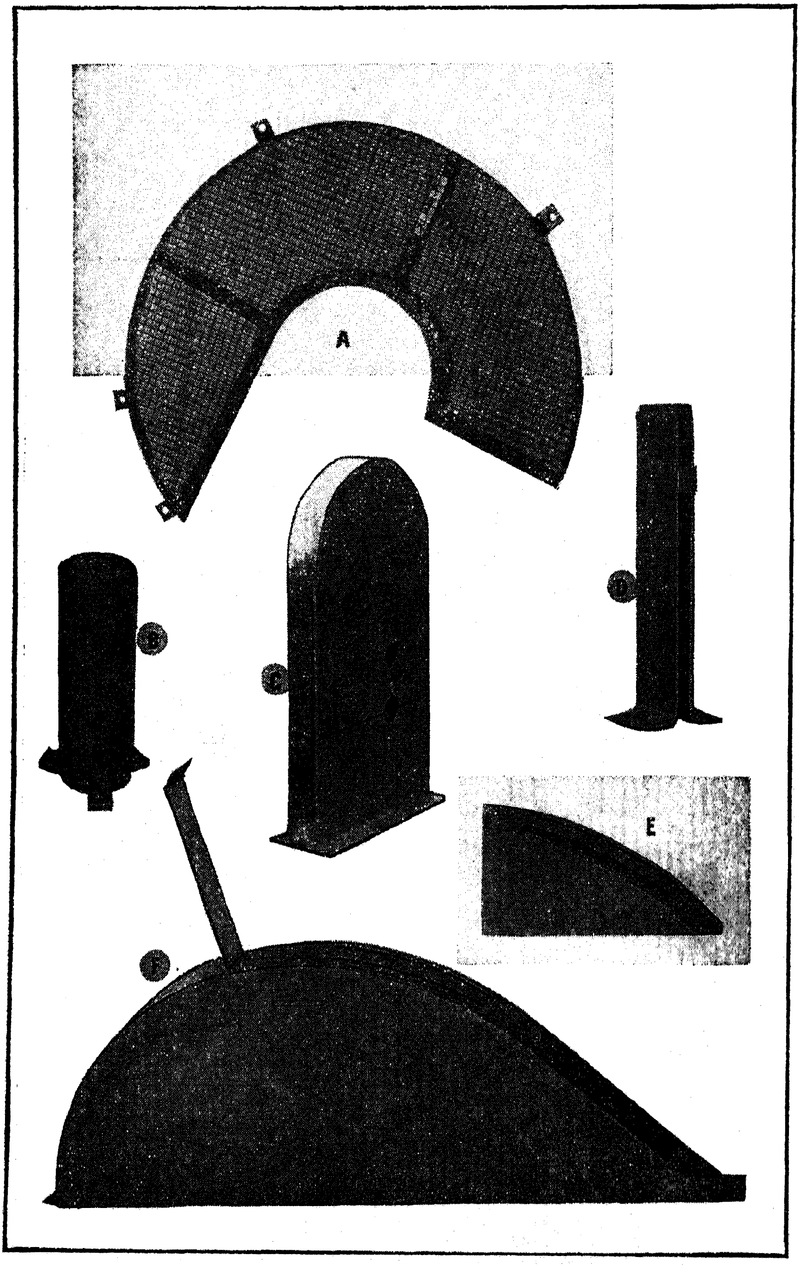


Fig. 1224. COVERS—(A) Fanguard for engine. (B) Cover guard for clutch shaft. (C) Chain guard on ice slinger. (D) Band saw guard. (E) Sliding door in gear guard for greasing. (F) Drum gear guard for crawler shovel.

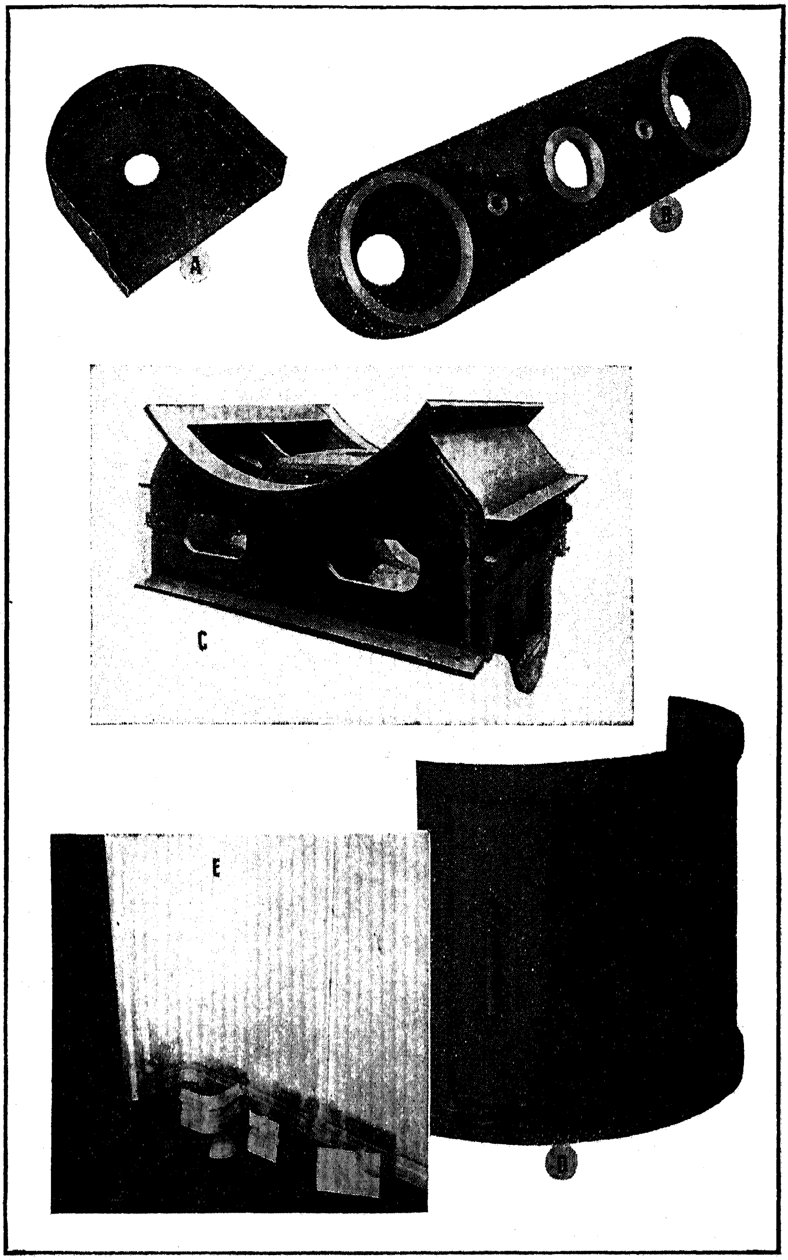


Fig. 1225. COVERS—(A) Disc saw guard. (B) Gearbox for road grader. (C) Locomotive smokebox saddle. (D) Cover for pulverizer mill. (E) Milk cooler cover showing stampings which are welded in to give vee'd groove.

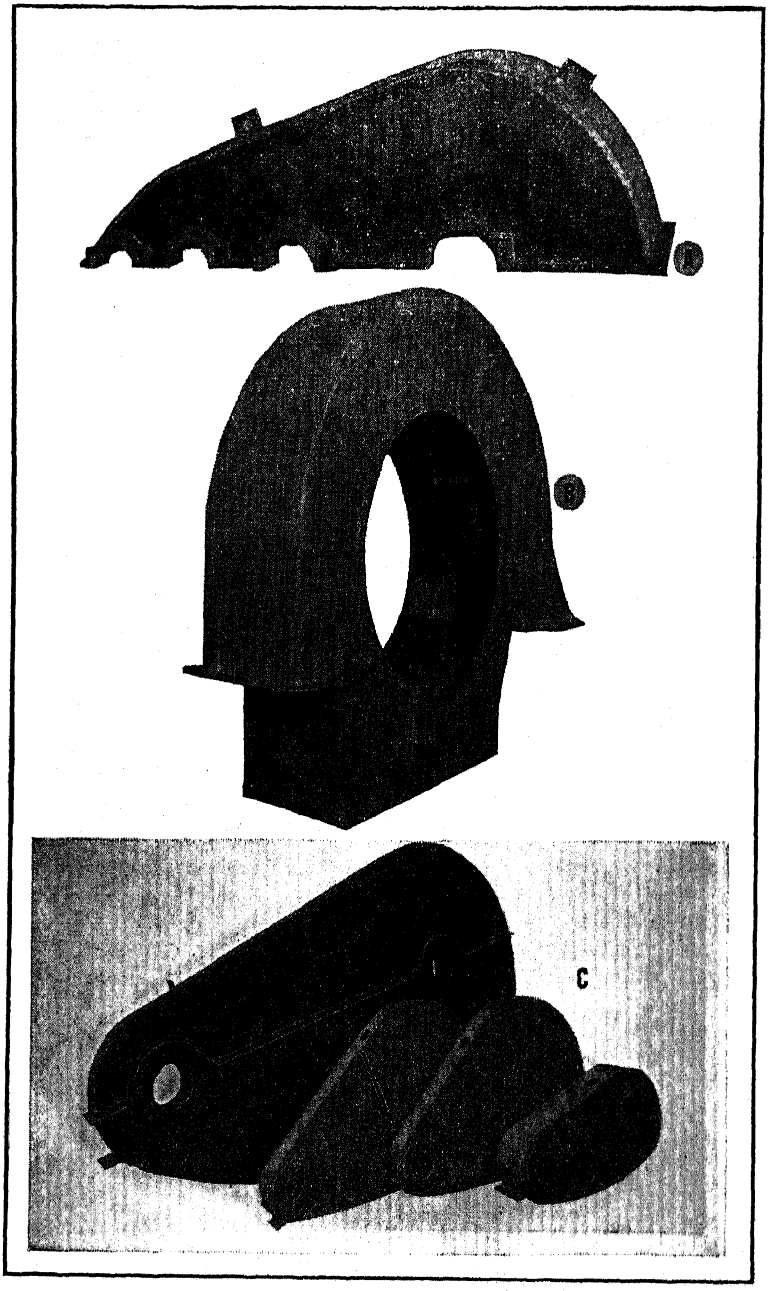


Fig. 1226. COVERS—(A) Cover for rolling mill drive, weight 4,000 lbs. (B) Generator casing. (C) Chain guards of various sizes.

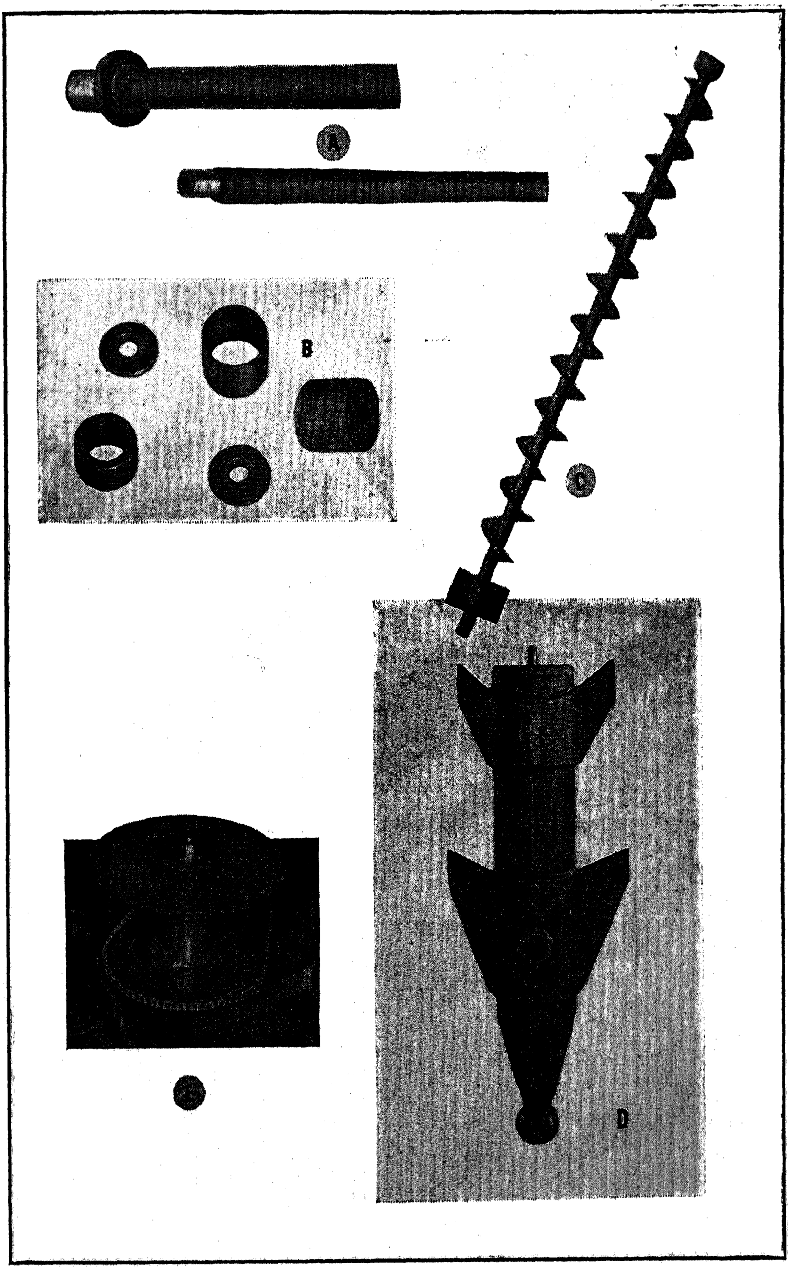


Fig. 1227. MISC. PARTS—(A) Main drive shaft for harvester. (B) Pulley for idling device. (C) Screw conveyor for harvester. (D) Front post of a road grader. (E) Chain-driven drum gauge.

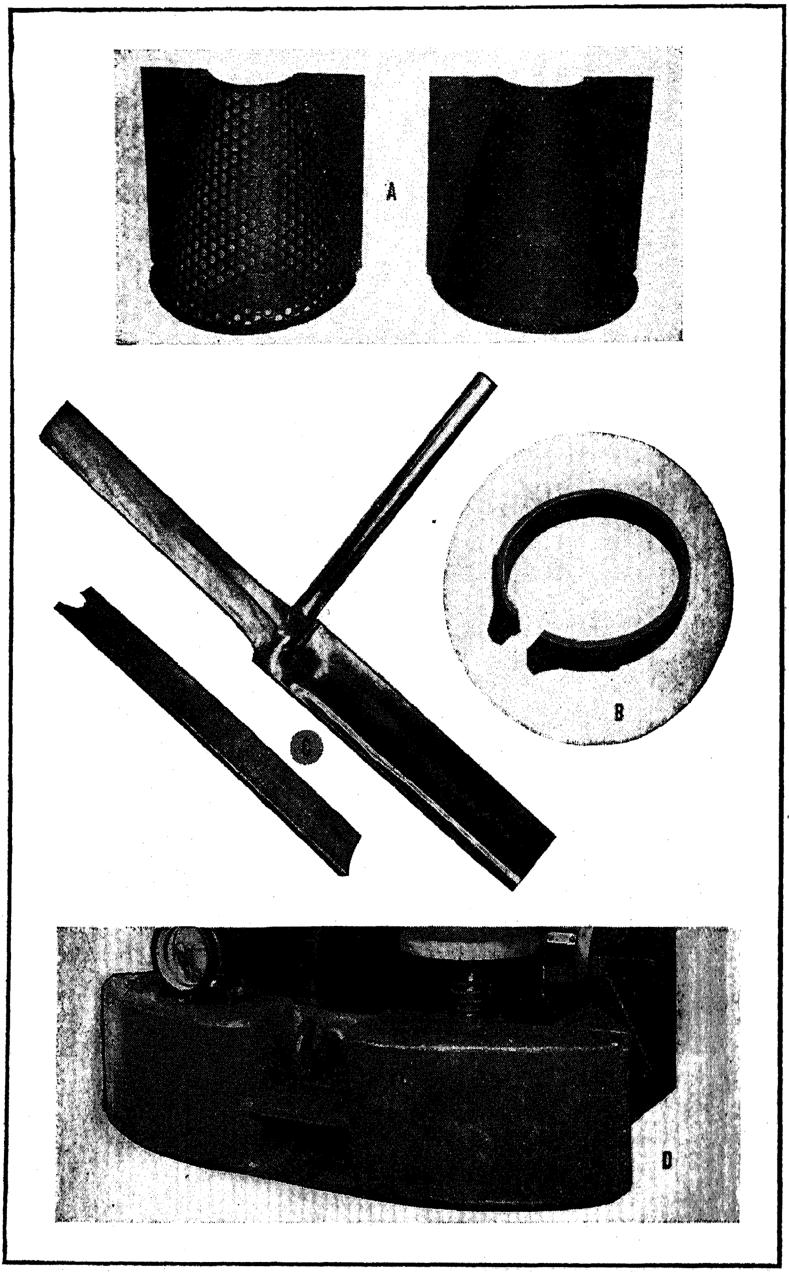


Fig. 1228. MISC. PARTS—(A) Segregating screens for grain mill. (B) Brake band for mining locomotive. (C) Mixing propeller for pasteurizer. (D) Bumper for mining locomotive.

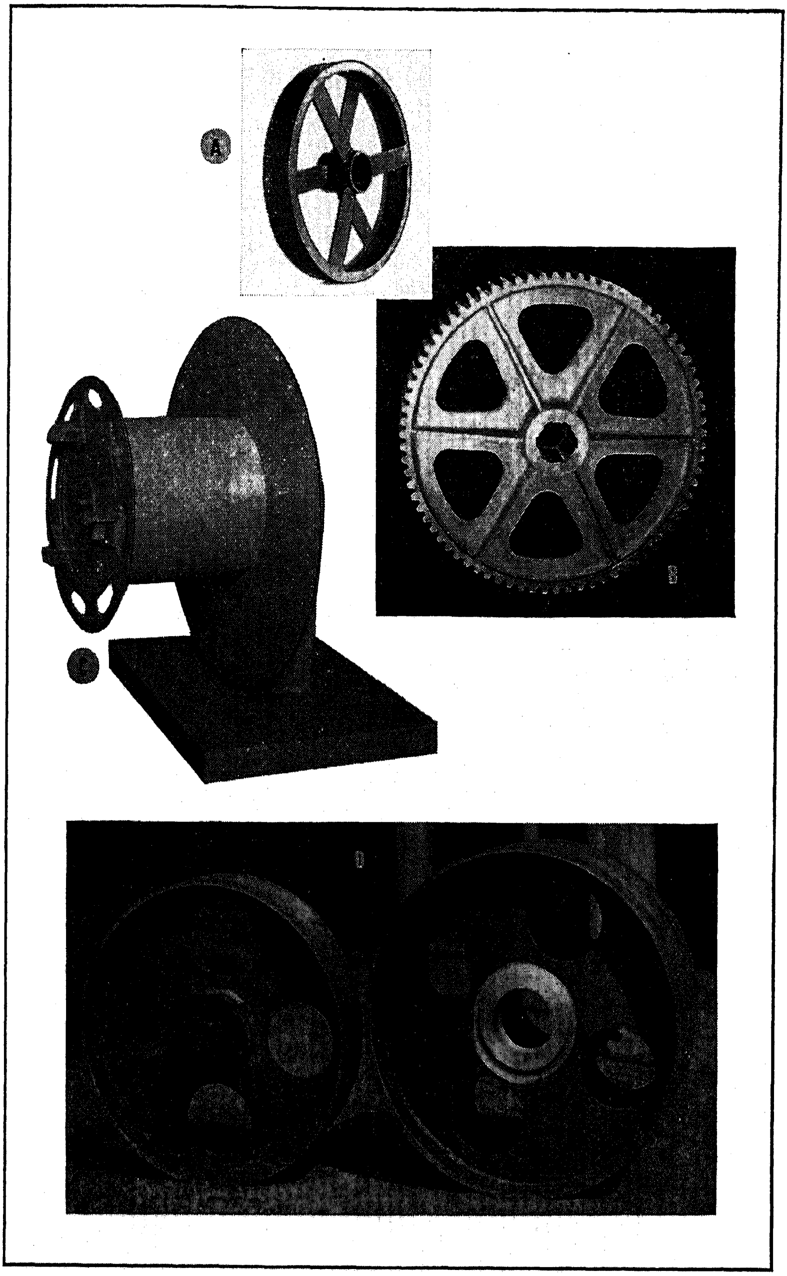


Fig. 1229. MISC. PARTS—(A) Wheel for hand-truck. (B) Small spur gear. (C) Wire reel. (D) Pair of shovel wheels.

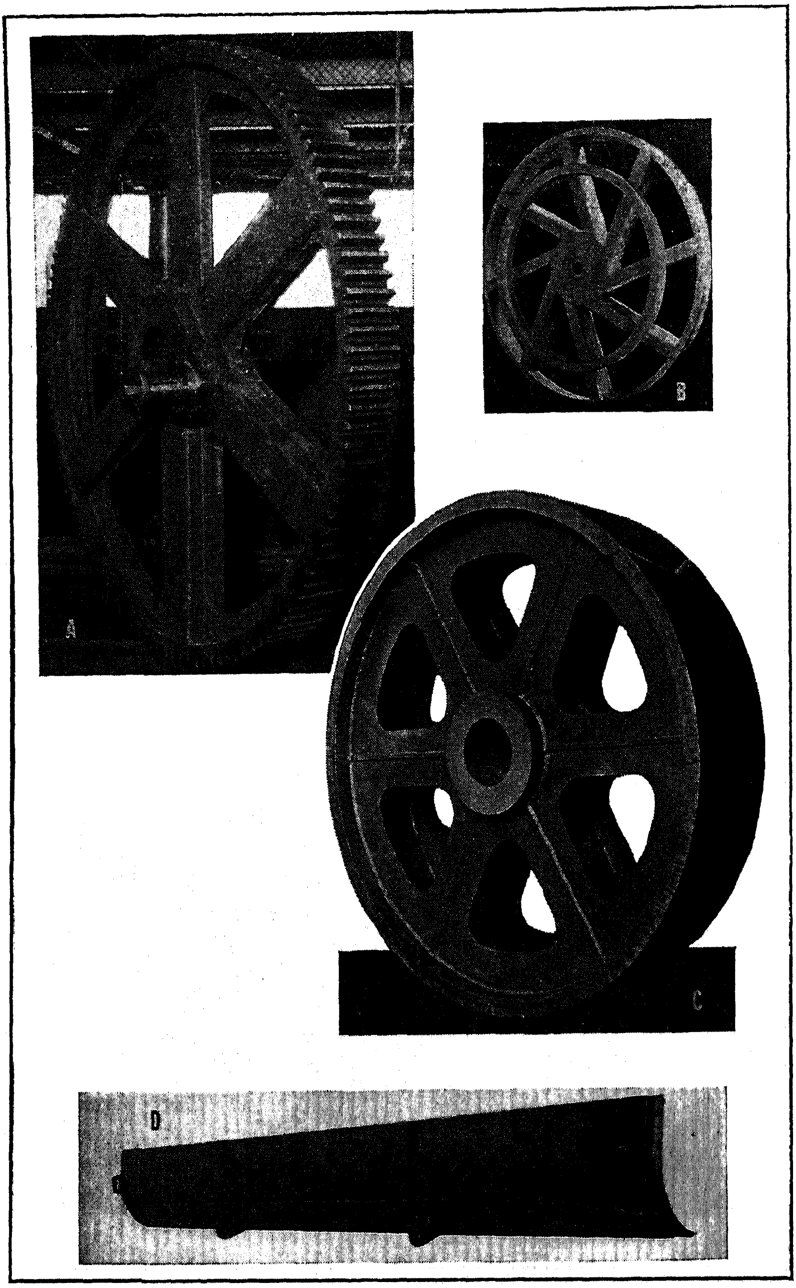


Fig. 1230. MISC. PARTS—(A) 12-ft. fabricated steel gear. (B) Band-wheel and tug rim (C) 5-ton gear blank. (D) Mold board for road grader.

Machine Tools

Arc welded steel is being employed in ever increasing amounts to the building of machine tools such as presses, brakes, shears, lathes, punches, etc., in order to secure the benefits of increased strength, rigidity and light weight for improved operating economies. This wide usage is conclusive proof of the superiority of welded steel construction in resisting stresses due to severe operating conditions. Notable manufacturing economies are also being realized by redesign for arc welding. Other advantages include simplified design, flexibility in manufacture and speedy production for quicker deliveries and improvements in appearance made possible by streamlining.

A few typical machine tools of arc welded construction are shown on the following pages.

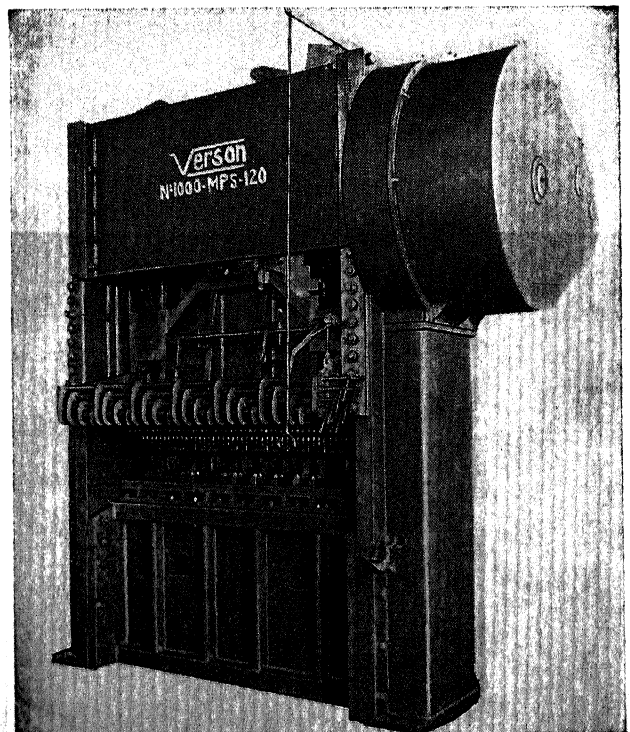


Fig. 1231. Multiple punch and shear, 1000-ton capacity, of arc welded steel construction. This machine is used in punching and shearing structural plate up to one-inch thickness.

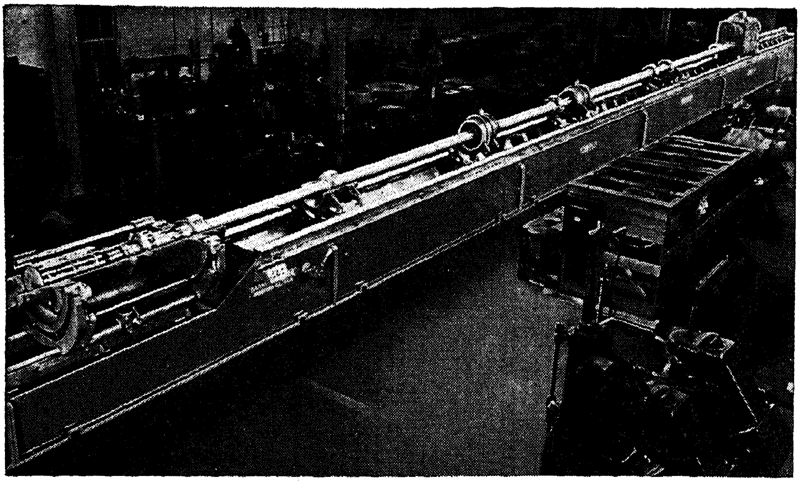


Fig. 1232. Spindle stroke honing machine, 76 ft. stroke, 30" bore said to be the longest machine of its type. Main bed is of arc welded steel construction.

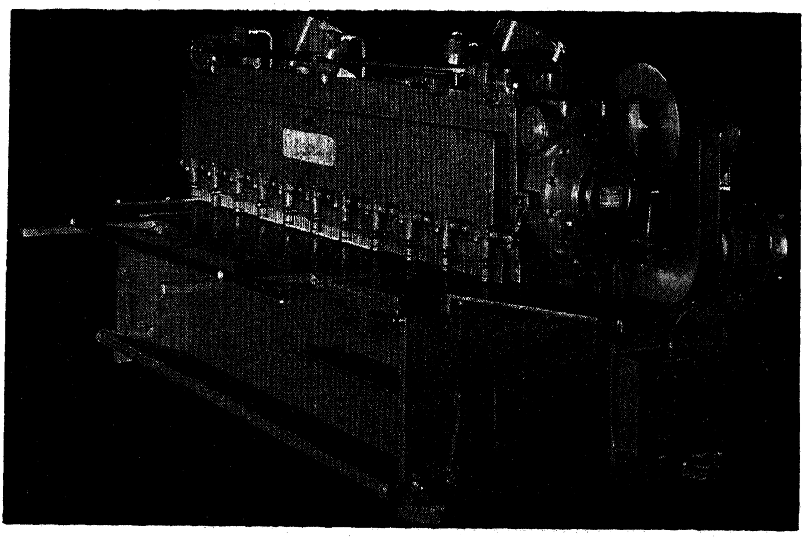


Fig. 1233. Bed top, drive gear, ram line H beam, housing, press connection, housing feet and gear guards of this 210 series x 15 ft. press brake are of arc welded steel construction.

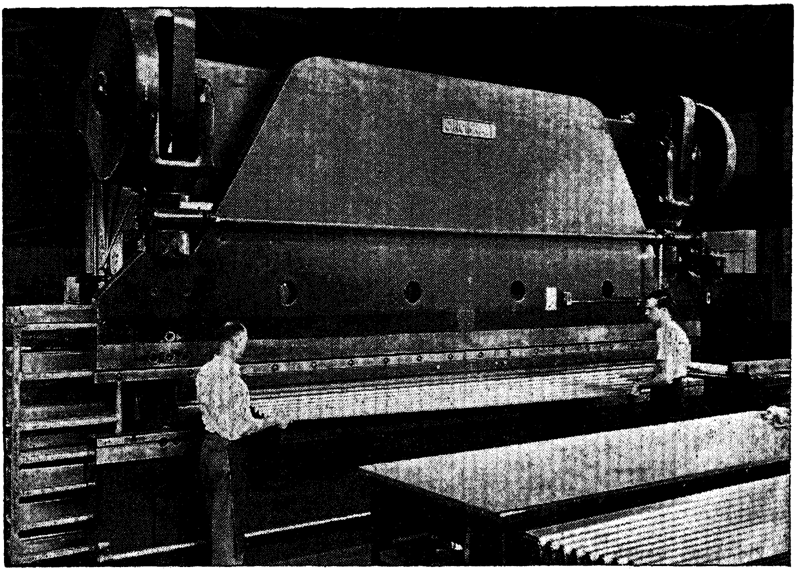


Fig. 1234. Housing feet, bed lugs, table box, ram brace, scrape chute and back gauge angles of this all steel shear are arc welded.

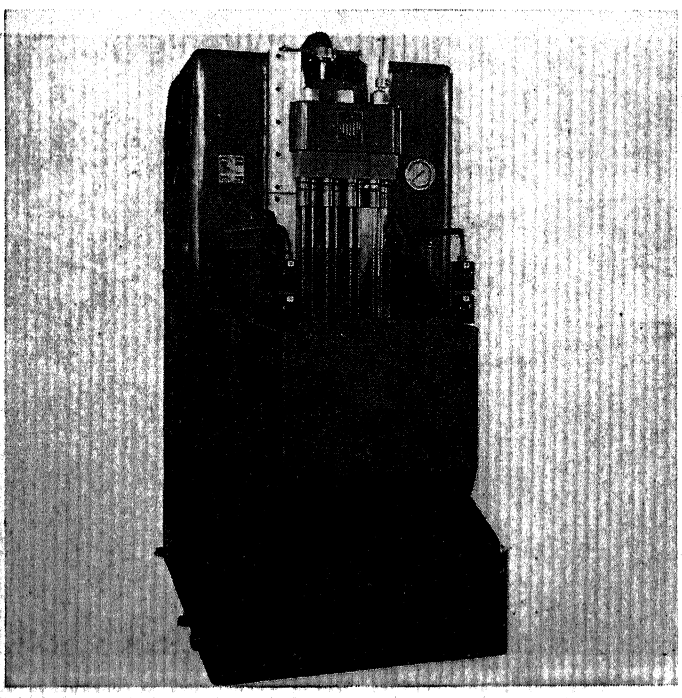


Fig. 1235. Hydraulic broaching machine of sturdy, streamlined arc welded steel construction.

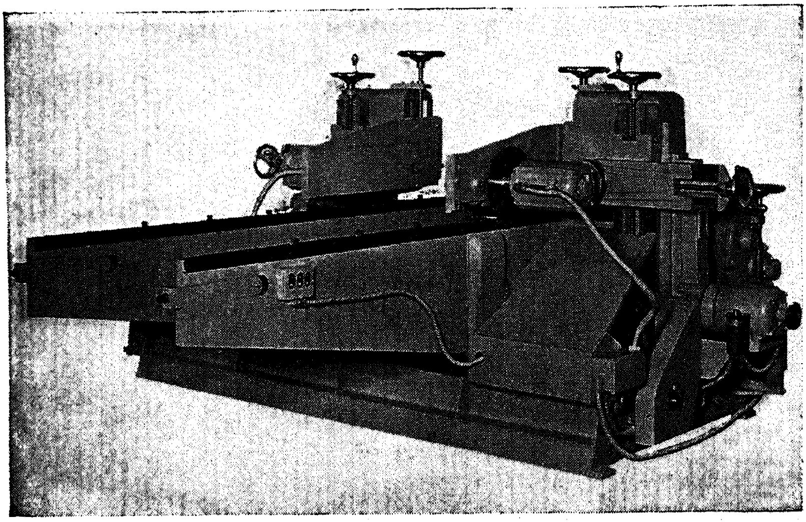


Fig. 1236. Double cut-off saw of arc welded construction. Weighs 5700 lbs. less than former construction, is stronger, costs less to build and has more pleasing appearance.

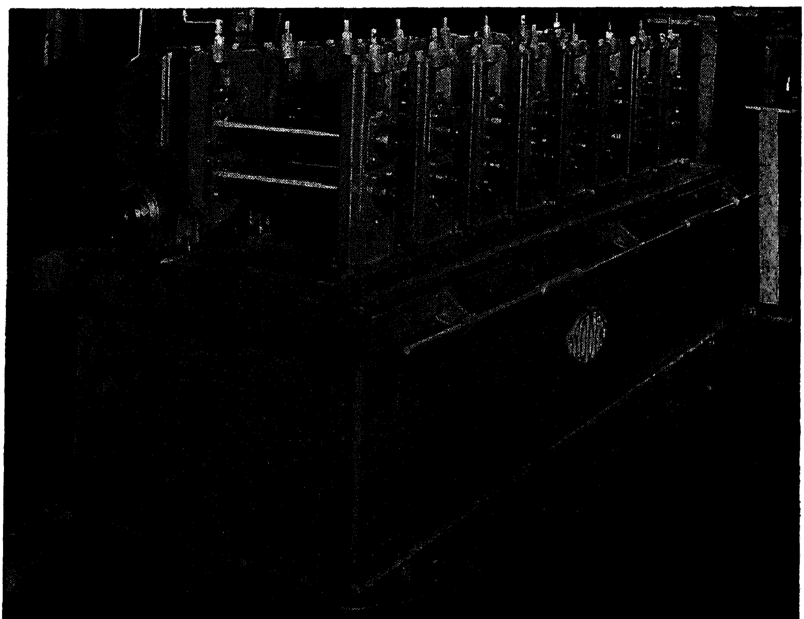


Fig. 1237. Cold roll forming machine. Use of welded steel in construction of base shortens average delivery time from 15 days to 5 days. Saves 33% in weight. Cost of completed welded base equals cost of patterns alone used for former construction.

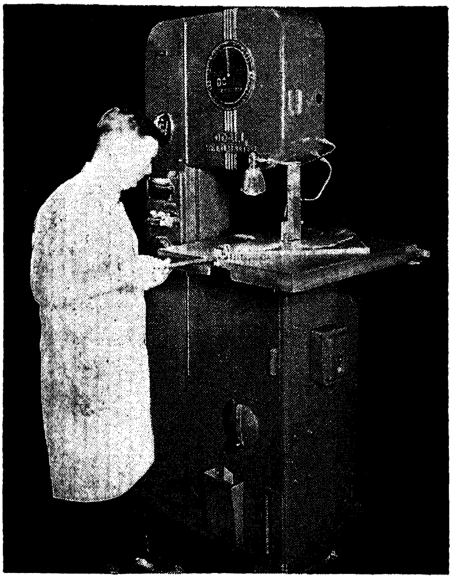


Fig. 1238. Contour sawing and filing machine. Welded steel model shown can do three times as much work as the cast model it replaces.

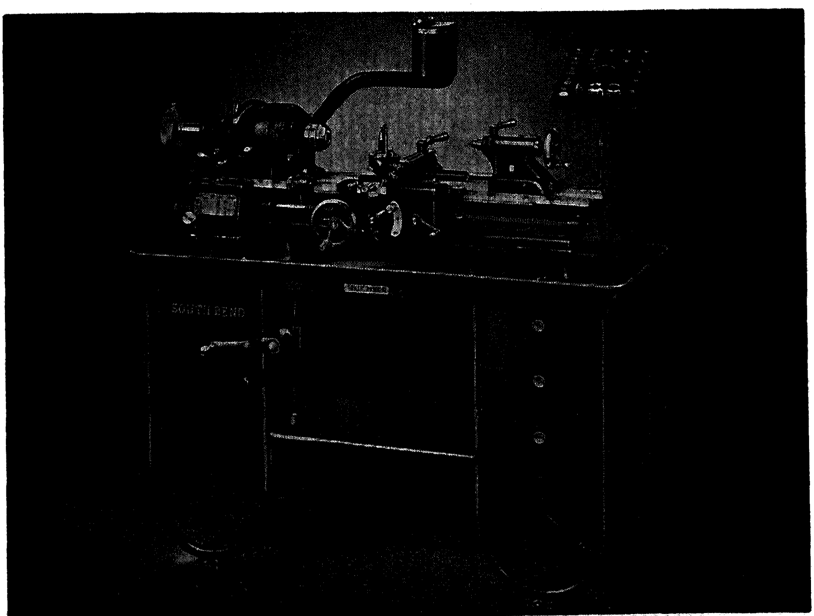


Fig. 1239. A unique bench design for a lathe providing pleasing appearance, made possible by arc welding.

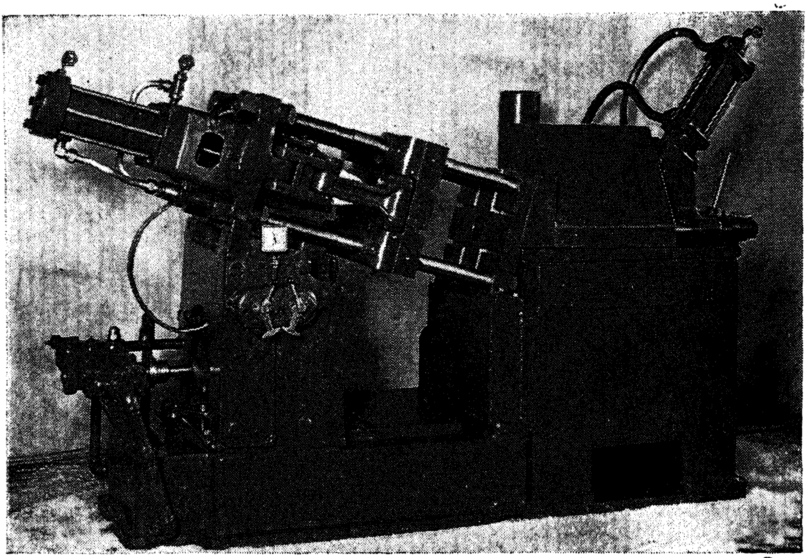


Fig. 1240. Arc welded steel is employed extensively in the construction of this die casting machine.

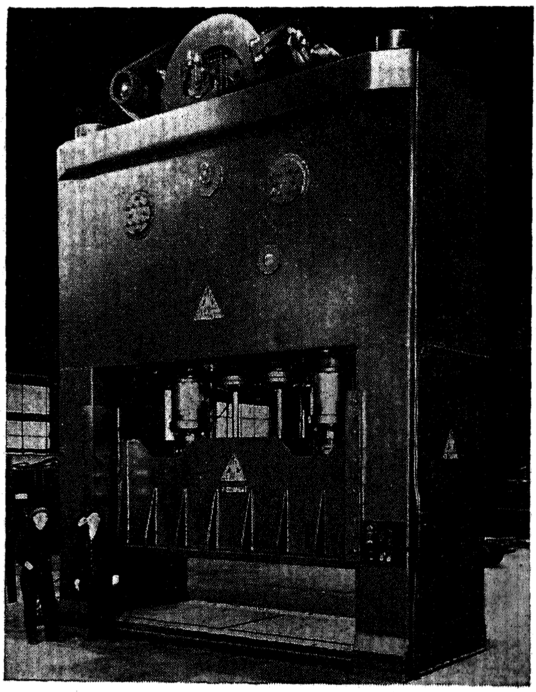


Fig. 1241. Completely fabricated, all welded steel press. Capacity 2200 tons. Distance between housing 164″. Typical application: forming steel ends for box cars.

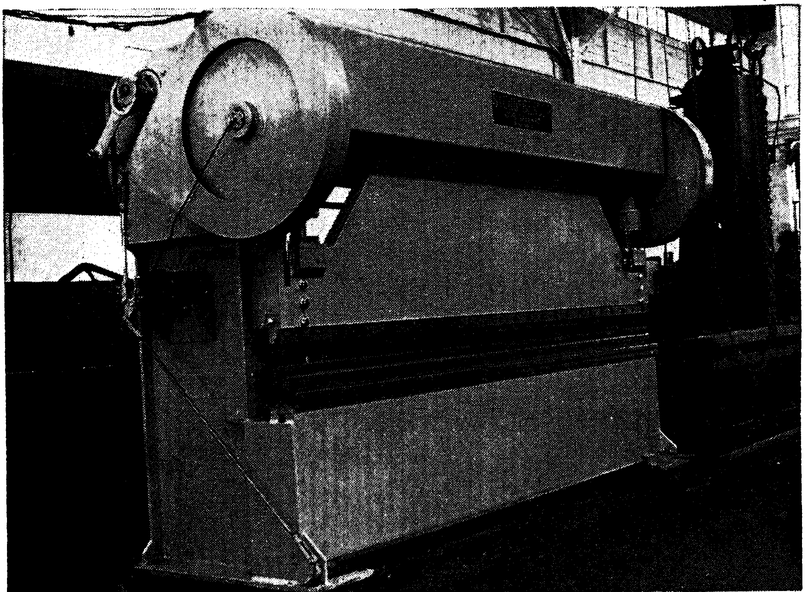


Fig. 1242. Bending press of all welded steel construction. The one-piece rigid steel frame takes heavy loads with minimum deflection, saving power and avoiding wear on ways and bearings.

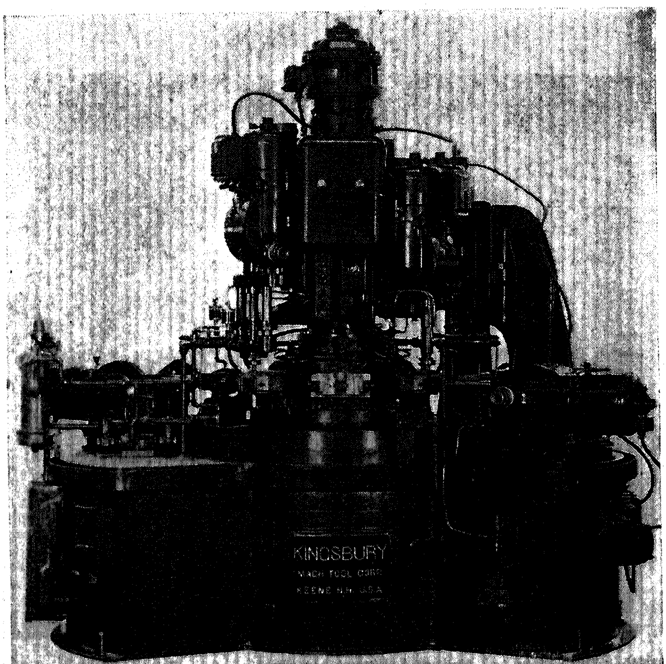


Fig. 1243. Welded steel base of this center column automatic indexing, drilling, reaming and threading machine is an interesting design.

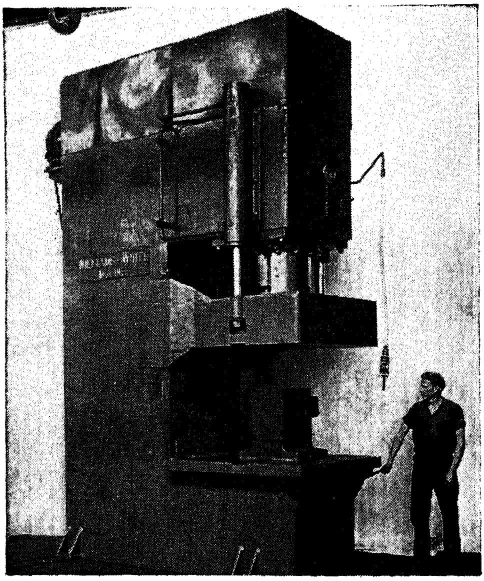


Fig. 1244. Frame and other members of this 500-ton hydraulic bending or crimping press are of welded construction for high strength, rigidity and light weight.

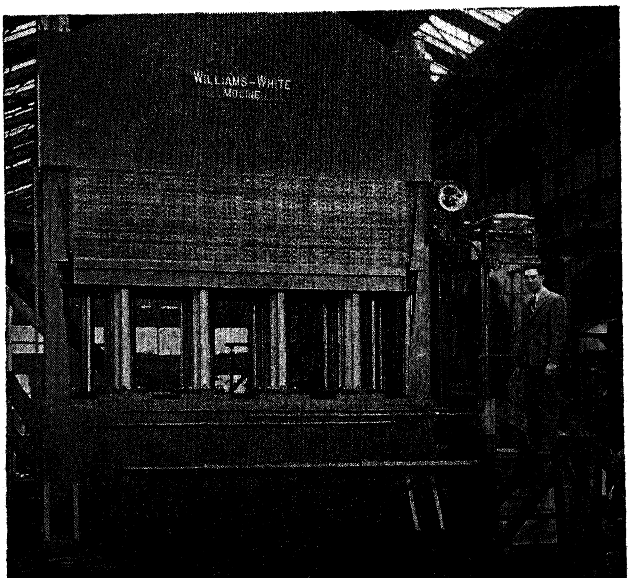


Fig. 1245. Deflection of top and bottom beams of this 819-ton hot plate press is minimized by use of welded steel construction.

Machinery — Miscellaneous

The following illustrations show a number of arc welded machines of interesting design in classifications not included in other parts of this chapter. In every case, both manufacturer and user benefit from several or all of the features of welded steel construction — strength, rigidity, light weight, quick delivery, low cost and pleasing appearance.

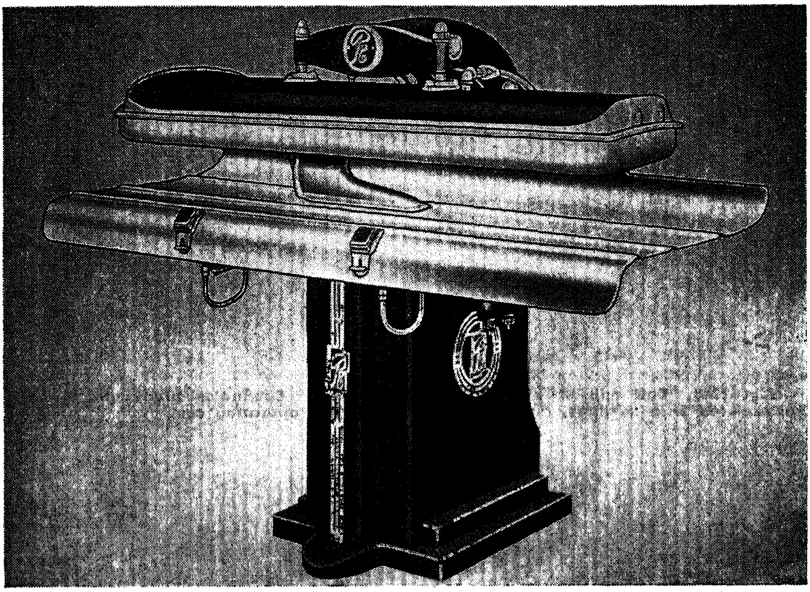


Fig. 1246. Laundry pressing machine. Redesign of frame of machine from bulky casting to welded steel construction cut weight 300 lbs. and effected savings of 16% in floor space. Increased rigidity of welded frame permits greater operating pressures for 40% greater laundry production. See Fig. 468.

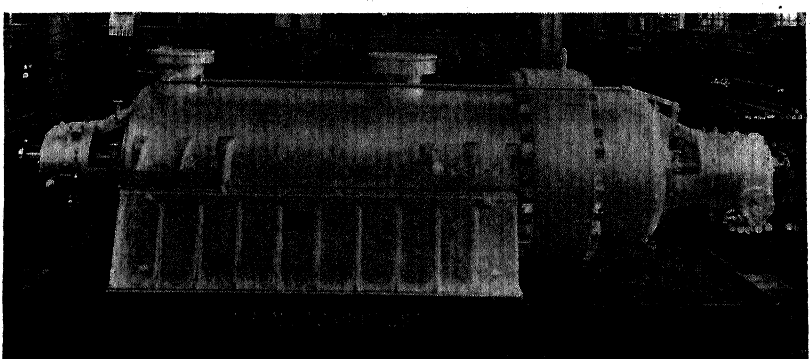


Fig. 1247. Centrifugal pump of welded steel construction designed to lift 887 g. p. m. to a head of 8275 ft.—said to be a world's record for this type of pump.

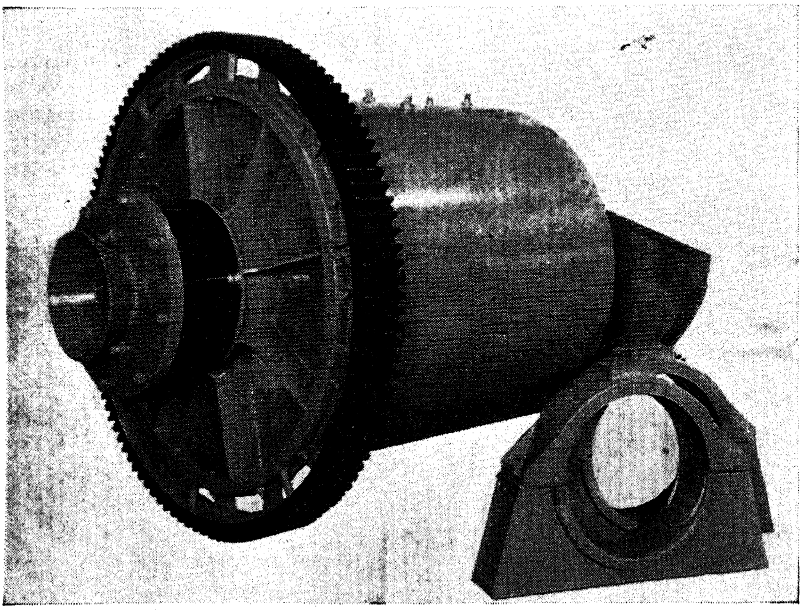


Fig. 1248. Ball mill of welded steel construction. Eliminates breakages formerly encountered with castings, and minimizes weight and operating cost.

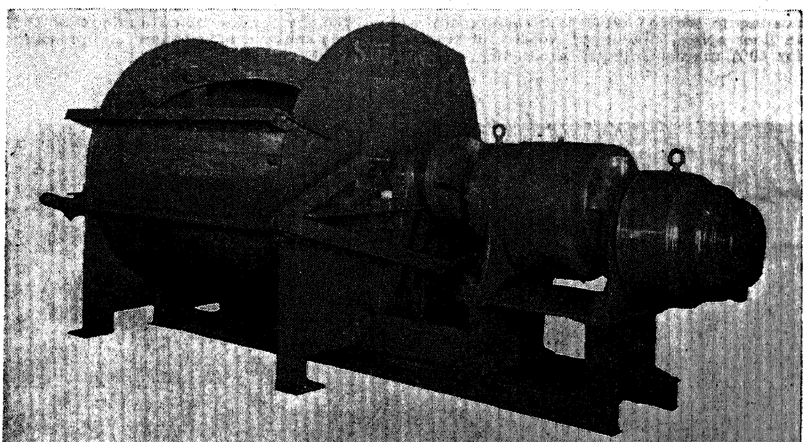


Fig. 1249. Concrete mixer used in conjunction with the forming machine shown in Fig. 1250, to produce concrete blocks, brick and tile. Built from steel plate and shapes by arc welding.

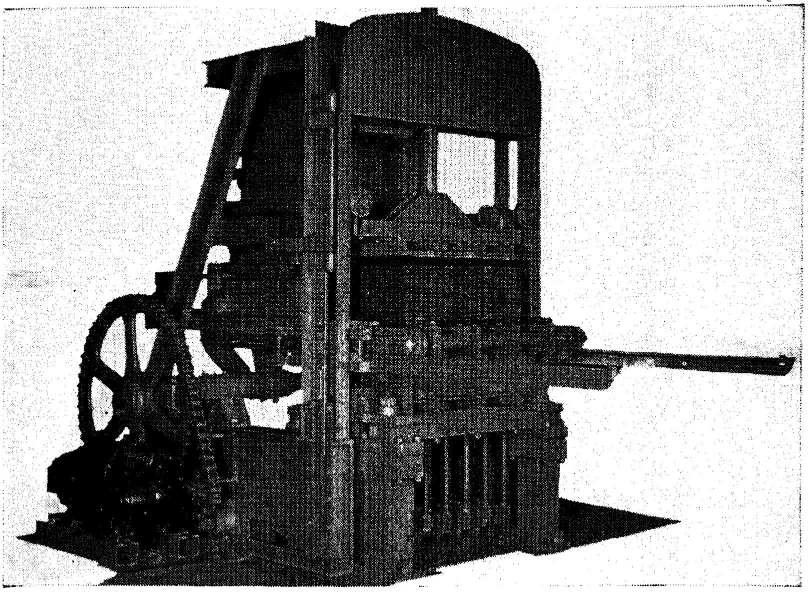


Fig. 1250. "Joltcrete," a machine used for forming concrete blocks. It operates on a principle of vibration rather than the conventional method of dumping, employing 7200 picking blows per minute for improved mixing and stronger concrete blocks. Arc welded steel construction is used to fullest extent possible to provide maximum strength, rigidity and economy.

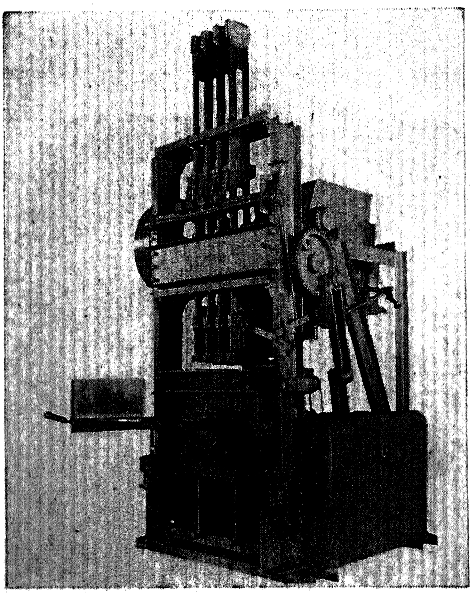


Fig. 1251. Power stripper used for forming concrete blocks. Shows interesting details of welded steel construction. Hard-facing with super abrasion resisting electrode, also employed on parts subject to abrasion and impact (on edges of tamps).

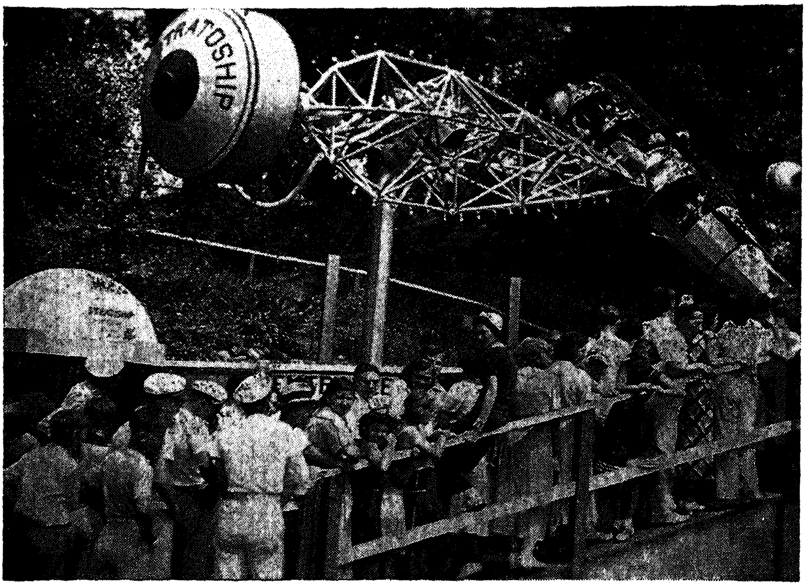


Fig. 1252. Many amusement park devices, such as the Stratoship shown, are built of welded steel for maximum strength, safety, light weight and pleasing appearance.

Fig. 1253. Conveyor washing machine for cleaning machine parts. Welding makes possible a streamlined design with an exceptionally strong, rigid framework.

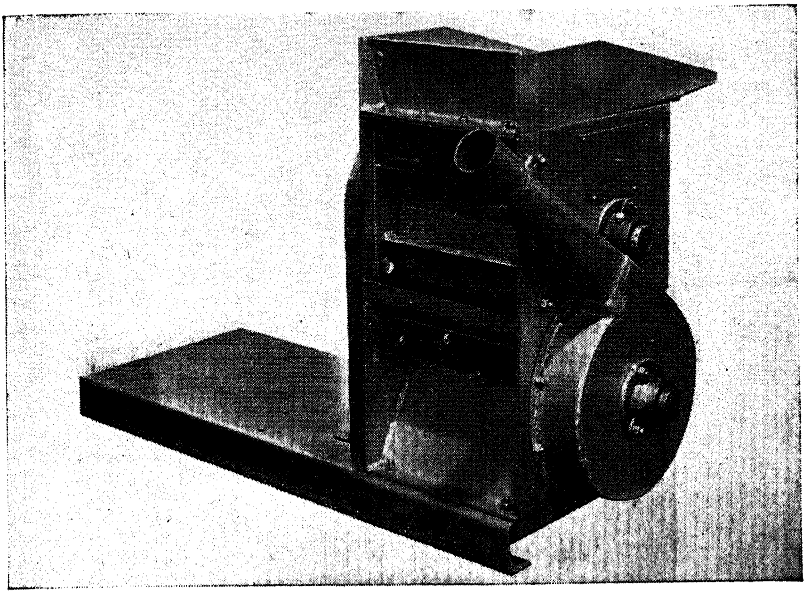


Fig. 1254. Ice slinger of welded construction built from shear cut and brake formed plate and standard mill shapes. Note simple, pleasing design of base.

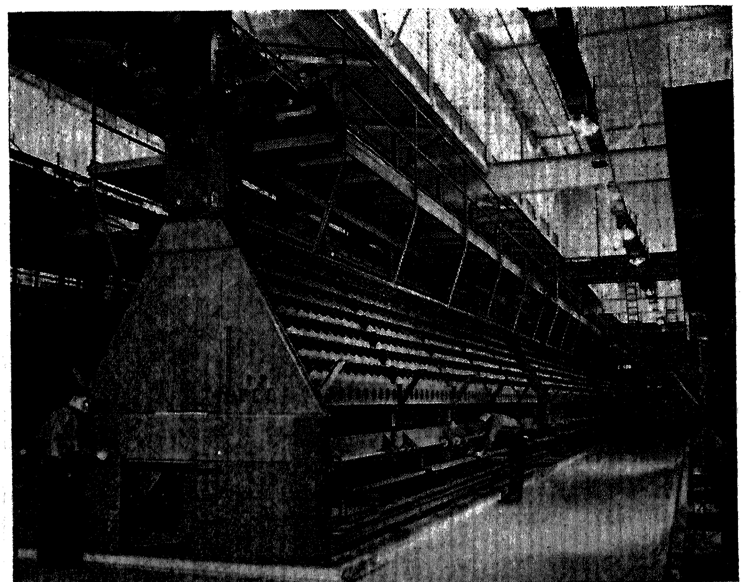


Fig. 1255. Arc welded construction of these continuous process rayon producing machines saved more than 67% over cast construction and made possible notable economies in performance.

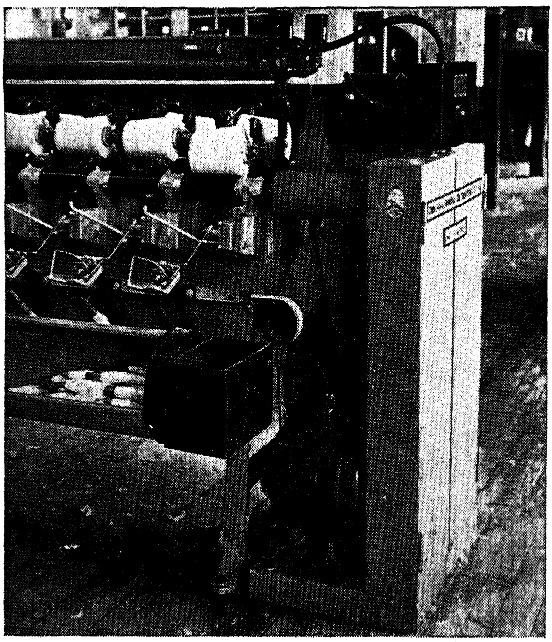


Fig. 1256. Drive end of this textile winding machine is of welded steel construction.

Maintenance—Miscellaneous

The repair of broken machinery and equipment parts was one of the first uses of electric arc welding. Since the introduction of shielded arc welding and the development of special electrodes for welding and hard-facing applications of all kinds, this maintenance tool has grown in use tremendously, saving millions of dollars annually for industry.

Arc welding is used by the maintenance department of thousands of mills, shops and construction projects in three ways, namely: (1) As a means of adding new metal to worn parts. (2) As a means of repairing broken parts of machinery and equipment. (3) As a means of building special production equipment, shop fixtures, machine parts and structures of all kinds. Many maintenance applications are illustrated and discussed in other sections of this chapter. The following illustrations show examples of a miscellaneous nature.

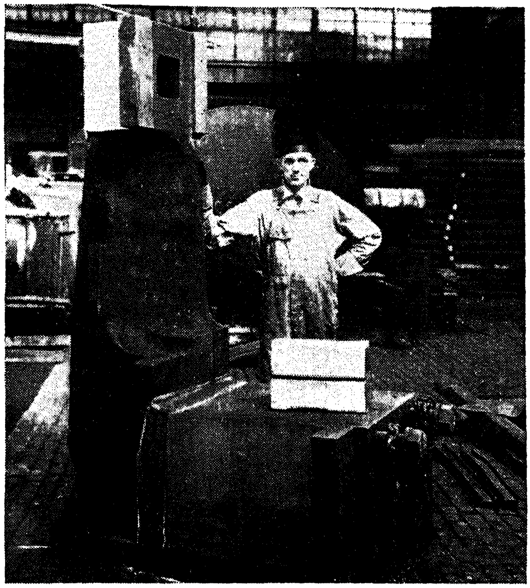


Fig. 1257. Repair of the cast steel frame of an upsetting machine. Break is shown by chalk mark. One weld is 6″ thick and 30″ long. Two welds are 2½″ thick and 24″ long. Skillful procedure by controlling expansion and contraction kept alignment of parts within .010″. Saved $1800.00 replacement cost and five weeks outage time.

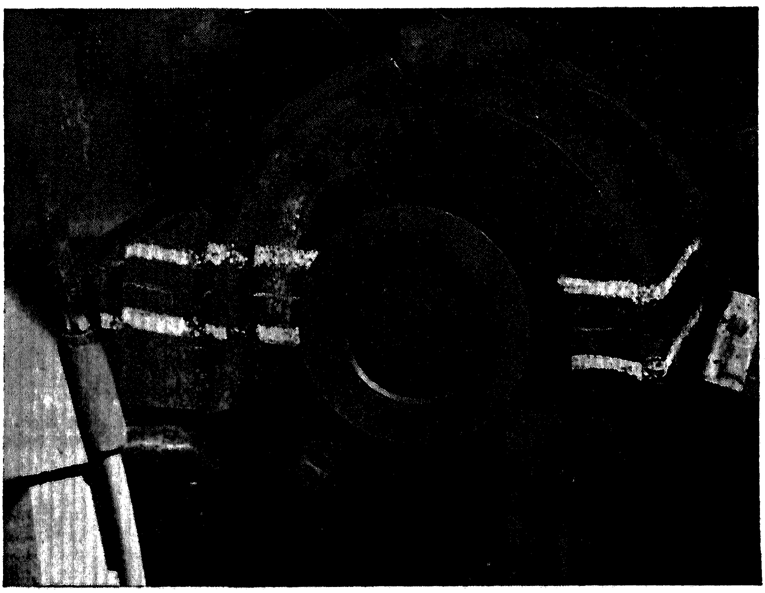


Fig. 1258. Broken bearing support of heavy shear. Crack was vee'd and welded, then reinforced with flame cut 1″ plate, welded to shear as shown.

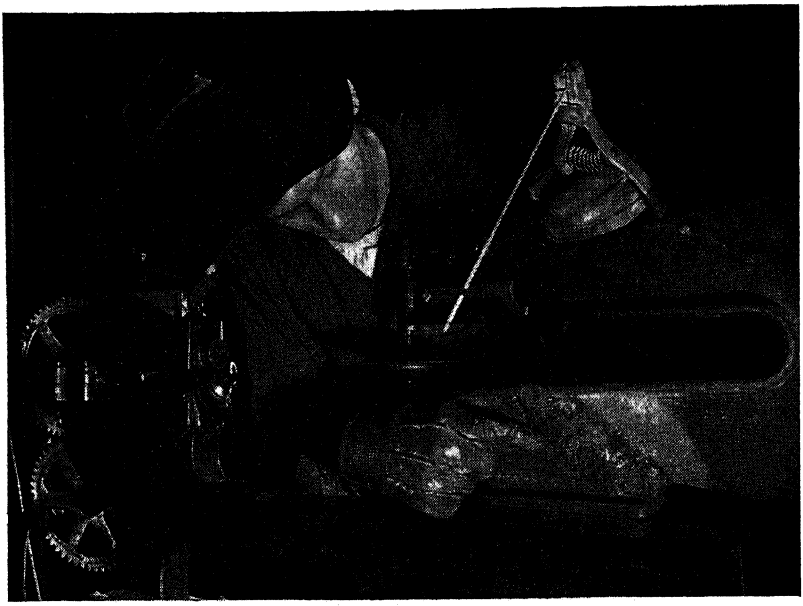


Fig. 1259. Cast iron frame of circular shear. Break was vee'd out and welded by the conventional cast iron procedure, (see Page 326), keeping casting as cool as possible.

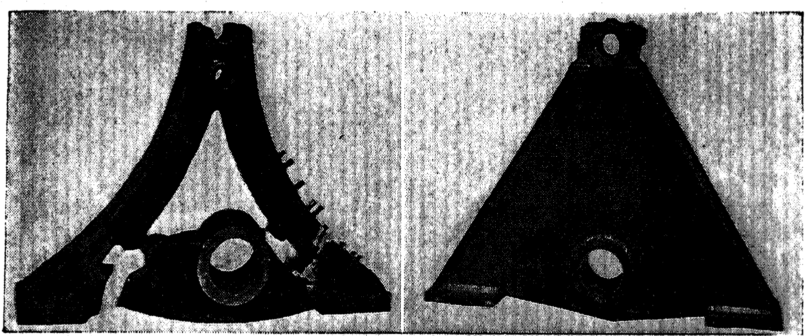


Fig. 1260. Broken bearing support for set of rolls (left) replaced with part shown at right, using welded construction with 3/4" mild steel plate. Saving 32% over replacement cost.

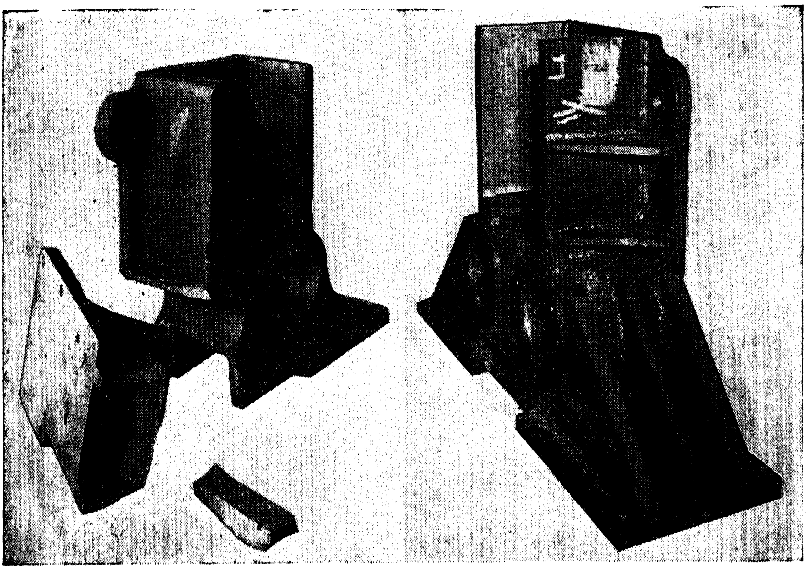


Fig. 1261. Broken housing for idler rolls weighing 1540 lbs. Replaced with welded steel design shown at right, weighing 640 lbs. Saved 60% over replacement cost.

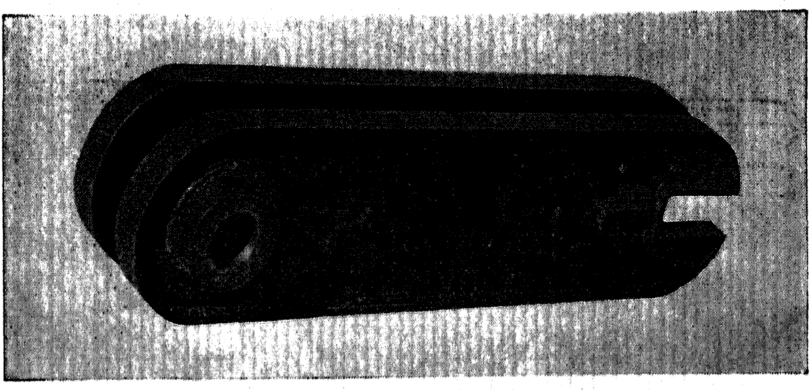


Fig. 1262. Housing for chain sprocket. Replaces broken casting. Fabricated from plate, bar stock and pipe as shown. Forestalled serious delay and saved \$8.70.

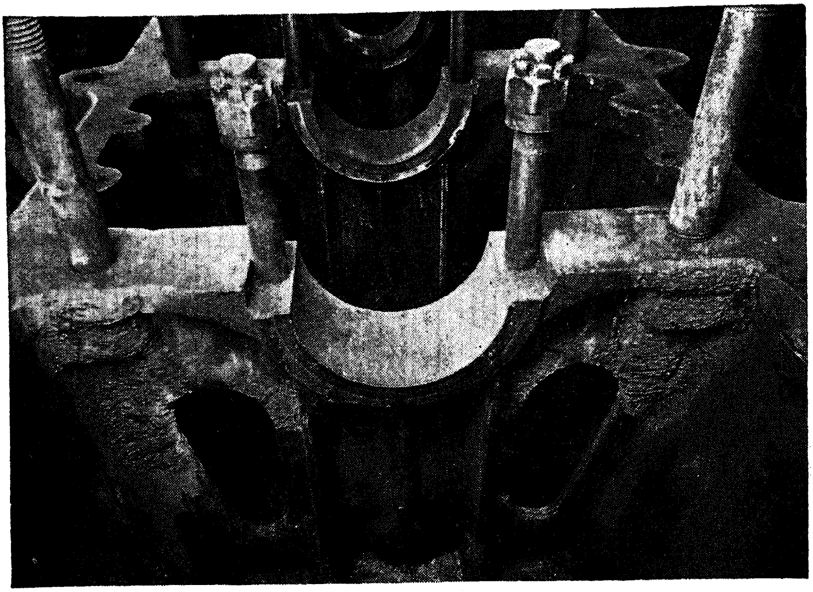


Fig. 1263. Close-up of weld repair in base of Diesel engine. Crack was vee'd out and studded. First layer was welded with cast iron type electrode. Subsequent layers made with mild steel electrode. Welded from both sides.

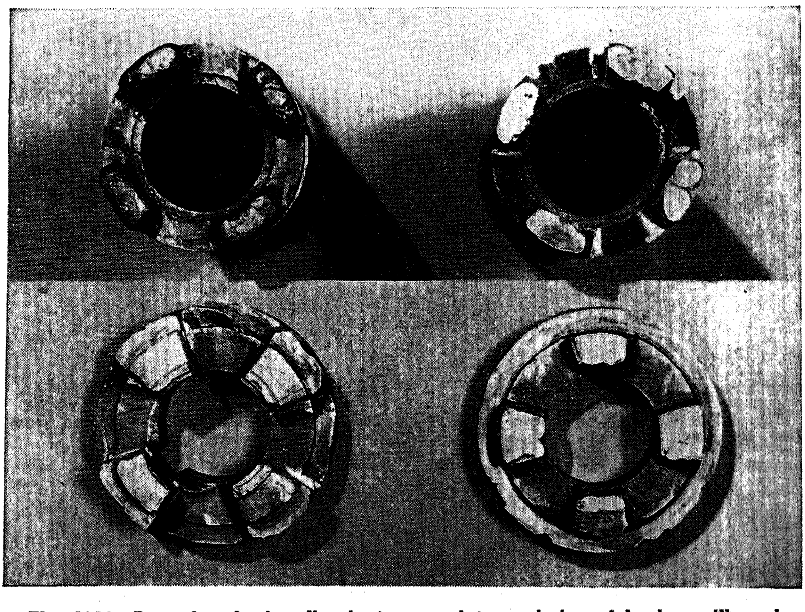


Fig. 1264. Parts for clutch collar in two-speed transmission of lumber mill engine. Worn prongs are built up with tool steel electrode, saving $9.00 per collar and greatly prolonging their life.

Materials Handling Equipment

Outstanding among the benefits of arc welded construction in the manufacture of materials handling equipment is the reduction in dead weight for greater pay loads. Also, in the case of equipment such as cranes, where long spans are encountered, the rigidity of welded steel makes possible improved designs and lower costs. Following are a few typical applications. See also Automotive Construction (Pages 764 to 784) and Watercraft (Pages 1064 to 1088).

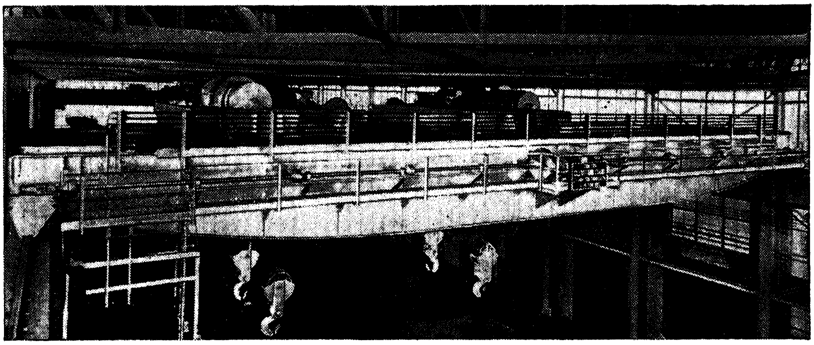


Fig. 1265. Traveling crane of 200-ton capacity and 100 ft. span of arc welded steel construction. Used in the plant of a large Diesel locomotive manufacturer.

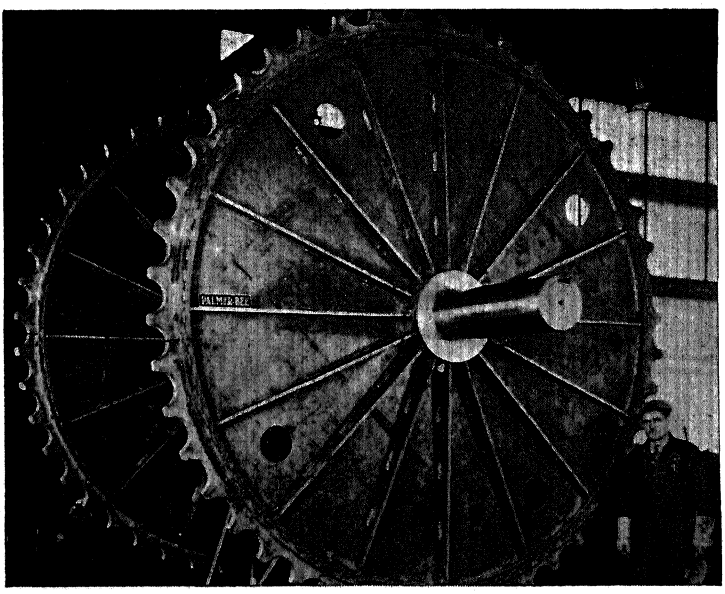


Fig. 1266. All welded steel sprocket used in a vertical core oven. Overall diameter 13 ft. Finished within a tolerance of 1/8".

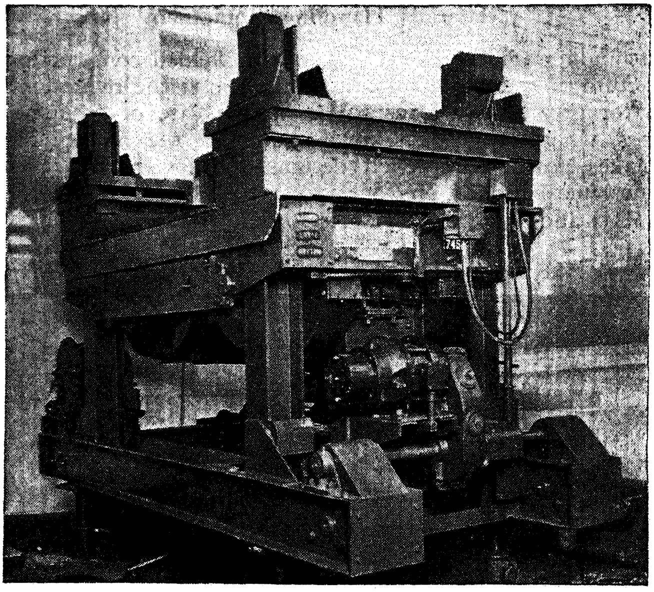


Fig. 1267. Lift table of welded steel construction for use in railroad roundhouse car shops.

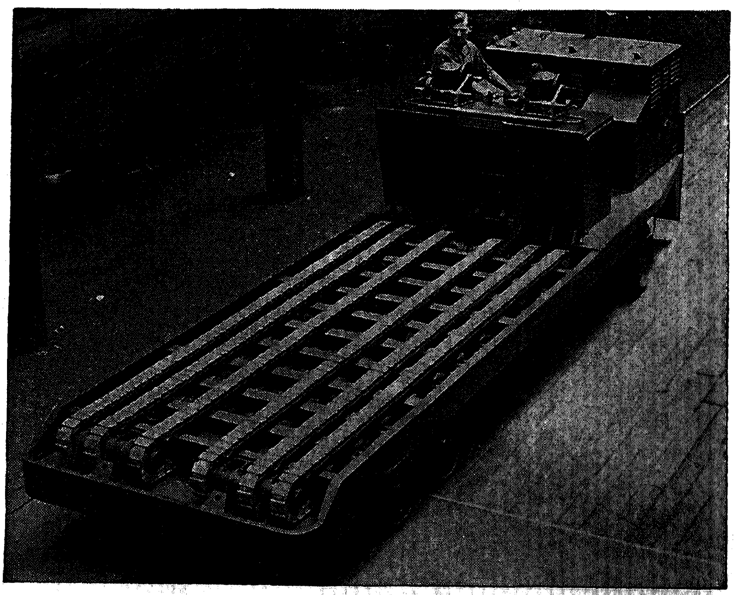


Fig. 1268. One of the largest industrial trucks ever built of welded steel construction. Capacity 40,000 lbs. Length 250", width 76". Built with standard structural shapes and plate, providing exceptional strength and rigidity with minimum weight.

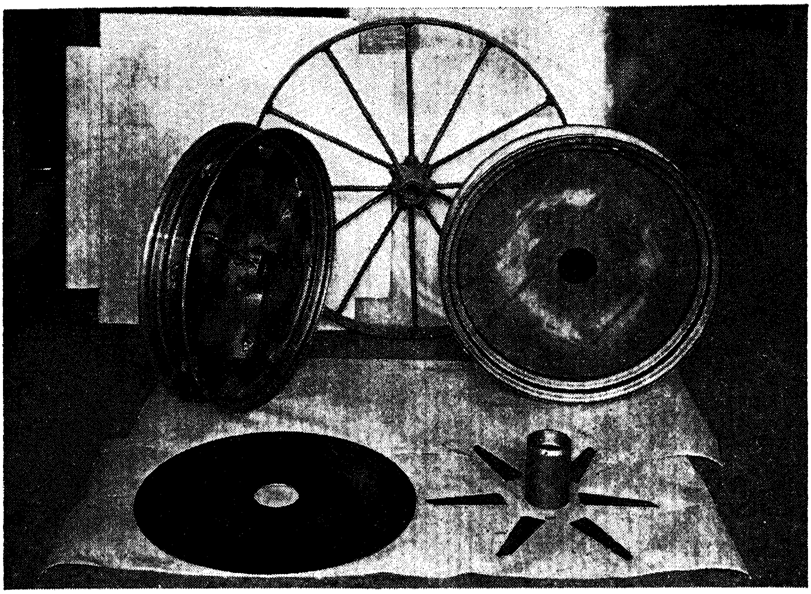


Fig. 1269. Wheel for a cement buggy. Former construction is shown in background. Welded steel construction, comprising pressed steel rim, plate disc and stiffeners and pipe hub gives modern design of pleasing appearance at low cost.

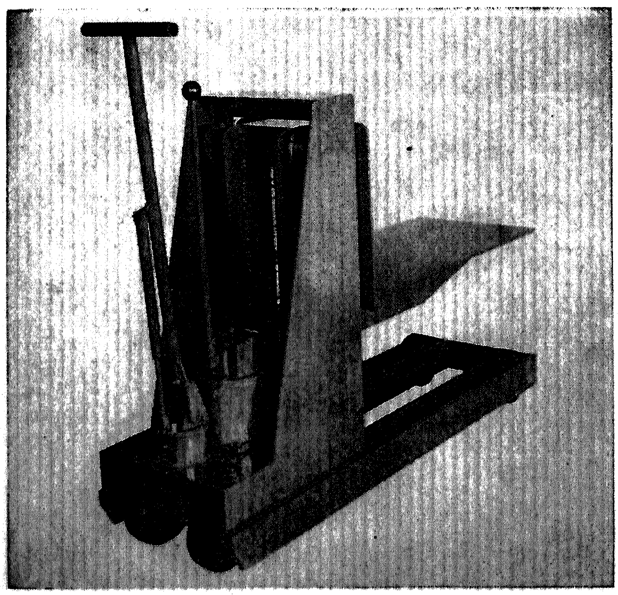


Fig. 1270. Lift truck of practically 100% welded steel construction. Welded design permits wide range of types and capacities with minimum production costs.

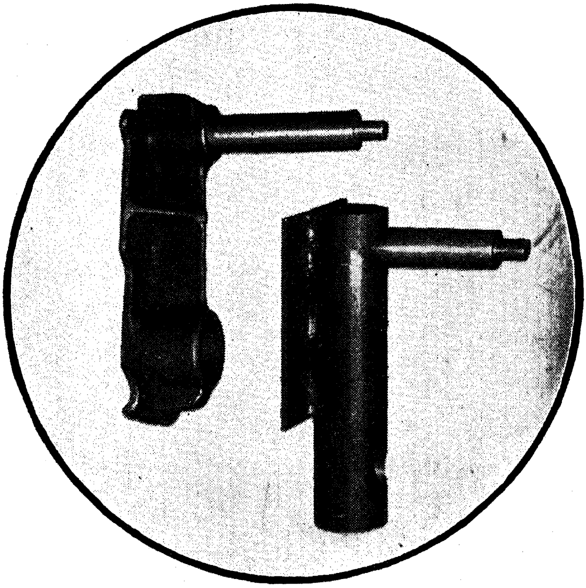


Fig. 1271. Bearing for a cement buggy. Former construction, shown on left, weighs 12 lbs. Welded steel construction weighs 8¼ lbs. and is unbreakable. Welding eliminates five drilling operations and one slotting operation.

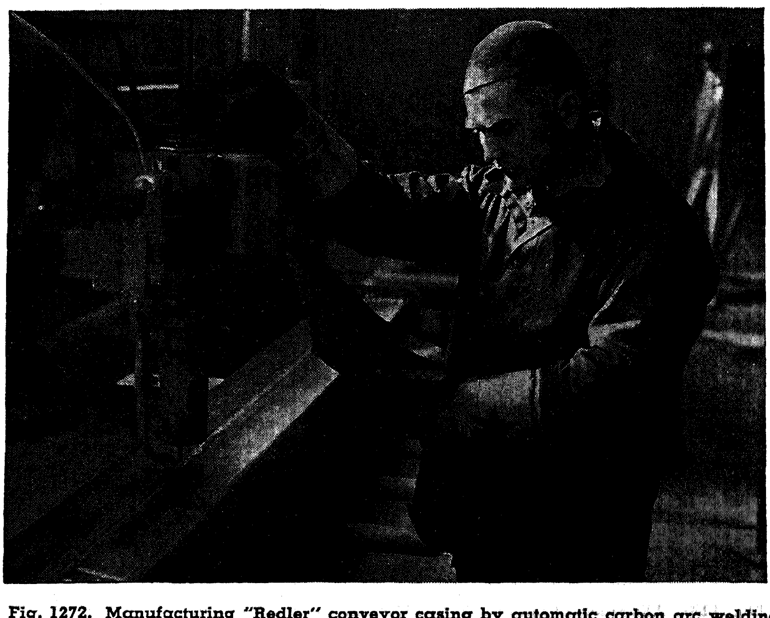


Fig. 1272. Manufacturing "Redler" conveyor casing by automatic carbon arc welding. This comprises two formed channels and a divider plate welded together.

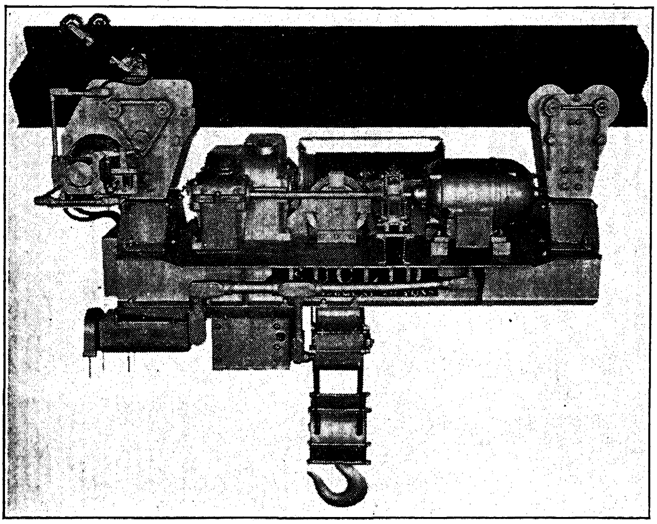


Fig. 1273. Floor-controlled electrically operated overhead monorail hoist of arc welded steel construction.

Fig. 1274. Side wall coal handling machine for an eastern railroad. Practically 100% welded steel construction.

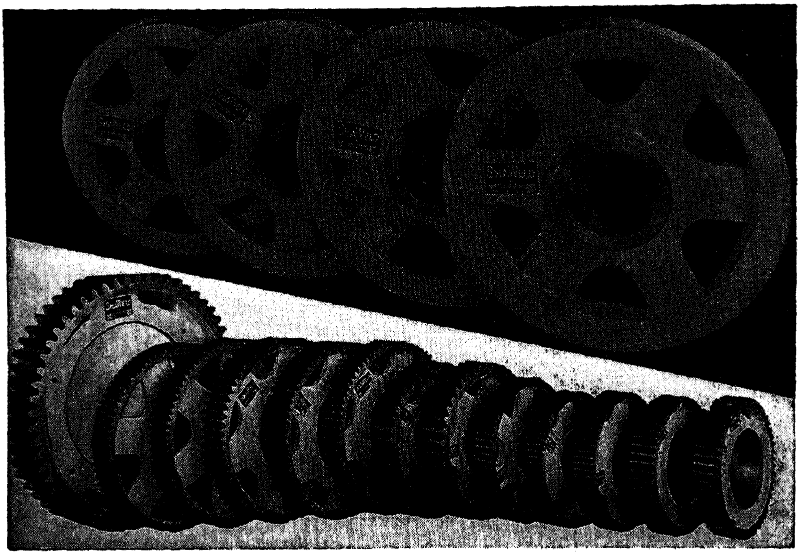


Fig. 1275. Welded steel gears and sheaves for materials handling equipment. Advantages: Cast savings are 10% to 25%. Quality is high, for various steels may be used in hubs, webs and rims to suit service requirements. Delivery time for special sizes is exceptionally short.

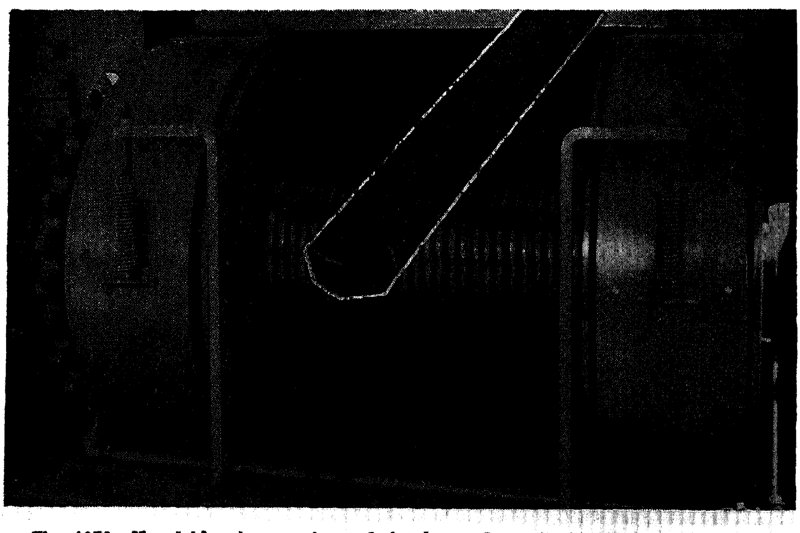


Fig. 1276. Novel idea in grooving a hoist drum. Instead of milling a groove in the drum, an alloy steel groove bar is wrapped around and welded to the drum. Avoids pinching of wire line for lower operating costs.

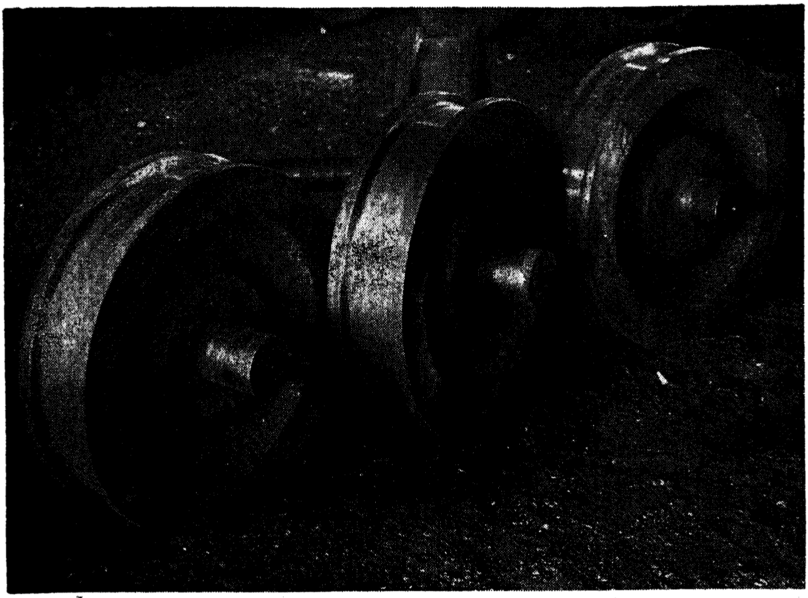


Fig. 1277. Crane wheels reclaimed with high carbon steel electrode at a cost of $30.00 each, saving $110.00 each. Worn surface is built up ½" then ground smooth.

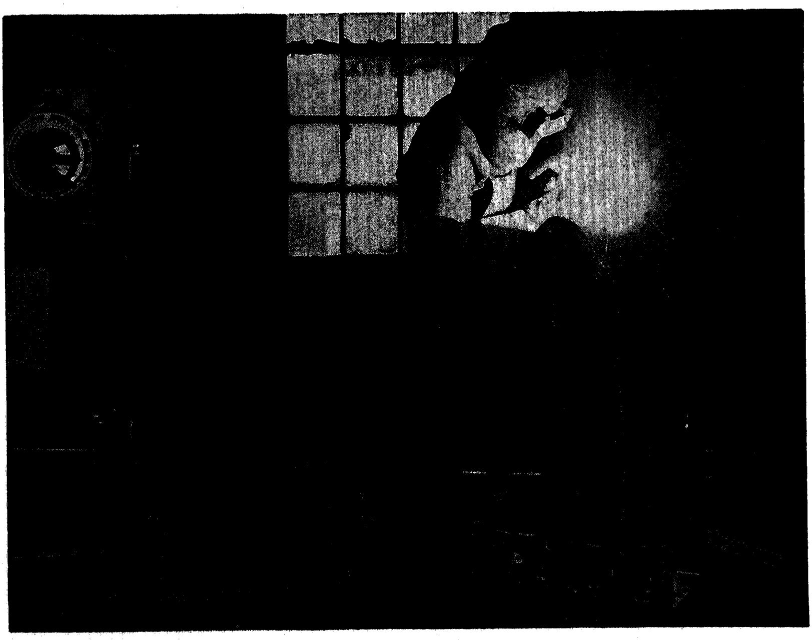


Fig. 1277-A. Replacement of this worn cast iron power wheel of a cement mill crane would have cost $550. It was built up by arc welding at a total cost of $125.

Mining Equipment

By specifying equipment of welded construction, coal and metal mines profit by securing maximum serviceability because of the strength, rigidity and tightness of arc welded joints. Moreover, especially in the case of materials handling equipment, costs are minimized because of the reduced dead weight of welded designs.

Because of the severe usage of mining equipment, arc welding is used extensively for the repair and reclamation of broken and worn parts. Typical applications include refacing of cutters, drills, bits, shafting, wheel treads, locomotive tires, gear teeth, frogs, switch points and rail ends. Mine maintenance shops also do considerable fabrication work in the replacement of broken parts and in the building of special equipment and structures, ranging in size from the coal tipple shown in Fig. 1286 down to the draw head shown in Fig. 1285.

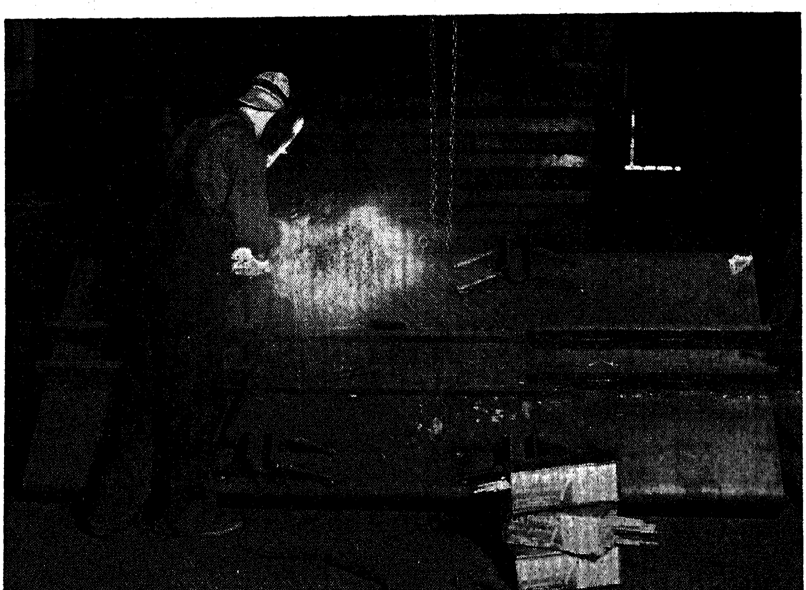


Fig. 1278. Rebuilding mine cars with welded steel in the maintenance department of a large coal mining company. This construction minimizes dead weight and because of this advantage, welded steel construction is often specified in the purchase of cars and other material handling equipment.

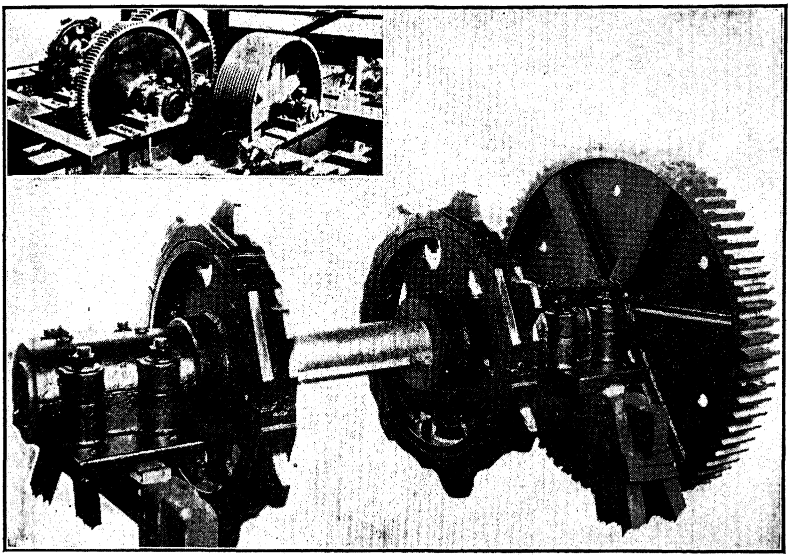


Fig. 1279. Sprockets and gear of this coal mine conveyor head shaft are of welded steel construction. The teeth are steel castings.

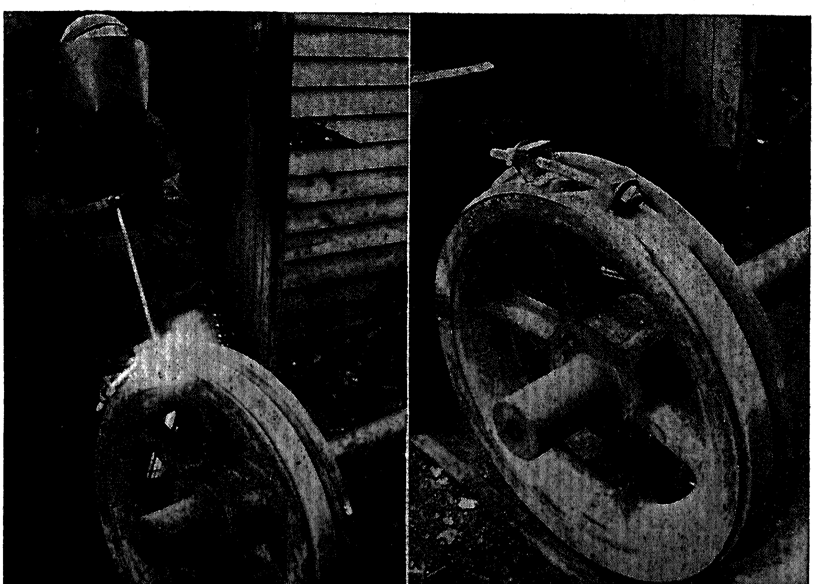


Fig. 1280. Building up worn locomotive tires. High carbon steel filler band is heated red hot, bent around the wheel and tightened by a clamping bolt as shown in inset. Tire is then built flush with shielded arc mild steel electrode. Average time per wheel is 2½ hours. Service of repaired wheels equals service of new wheels.

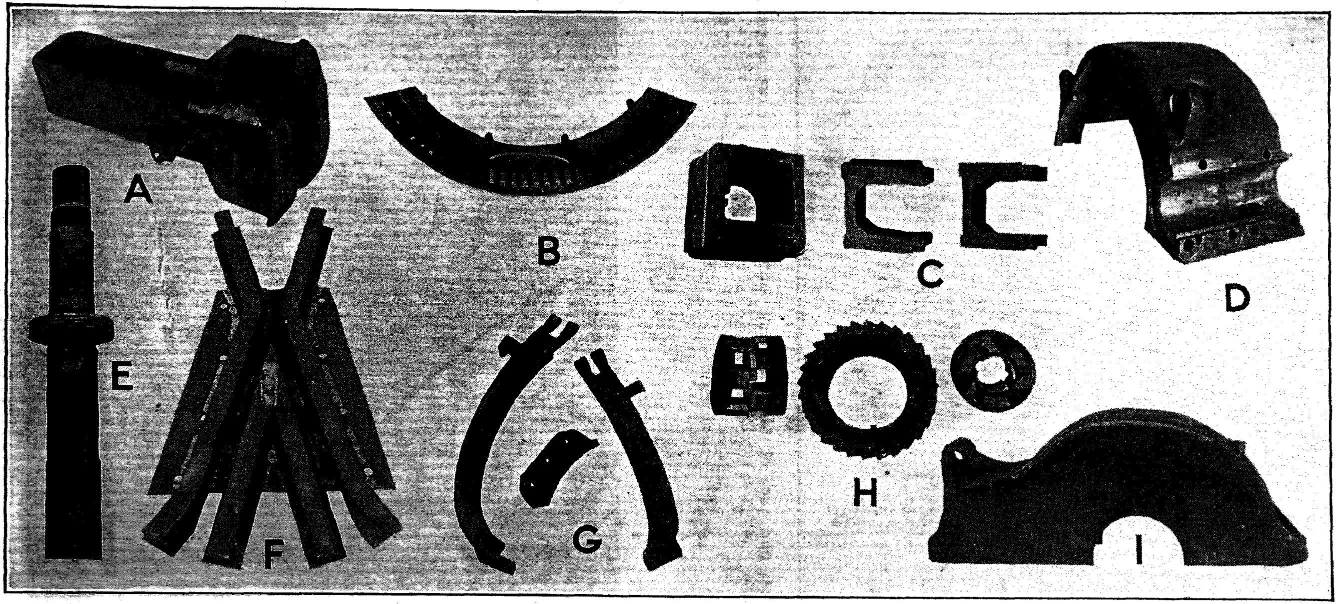


Fig. 1281. Group of parts reclaimed by arc welding. (A) Steel bumper for mine car fabricated and hard-surfaced at wearing faces. (B) Ring gear with teeth replaced by weld metal and case hardened. (C) Journal boxes for 13-ton locomotive (left) and 7-ton locomotive (center and right) reclaimed for only $8.17 and $5.51 respectively. (D) Gear case for mine locomotive with bearings and end bell built up and faced with mild steel weld metal. (E) Axle for mine car with threads rebuilt by applying weld metal and machining the threads. (F) Railway frog repaired at a saving of 50% by arc welding. (G) Steel brake band (right) made by welding for 75 cents and wooden band (left) which the steel band replaced. In center is an arc welded steel brake shoe made for 35 cents. (H) Clutch (left) for coal cutting machine with teeth lengthened by building up with weld metal and grinding to size. Clutch (right) has been built up by welding and then case hardened. In center is a bronze bevel gear for cutting machine with lugs on inside built up and case hardened. (I) Cast steel gear case for locomotive reclaimed for $2.50 by arc welding in a new steel side plate.

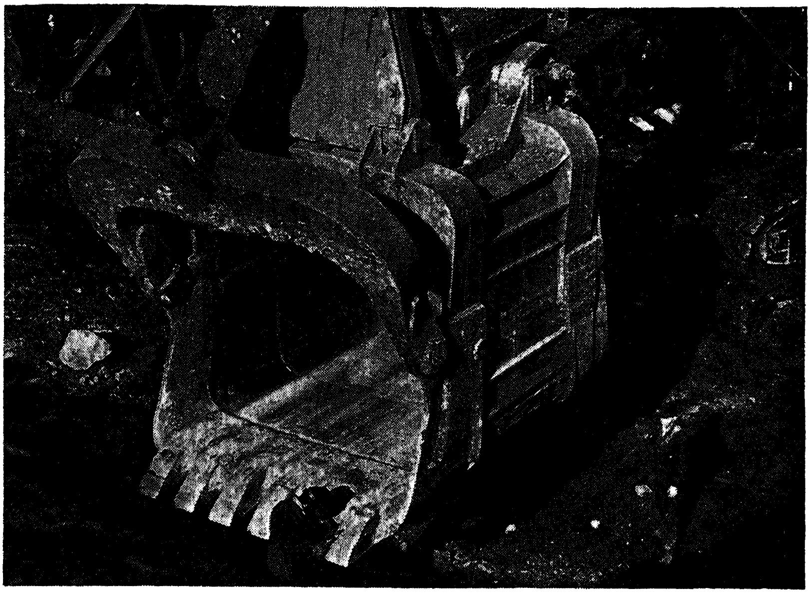


Fig. 1282. Building up worn dipper teeth of world's largest power shovel used in strip mining. Successive beads of super abrasion resisting electrode are laid cross-wise of the teeth covering faces and points.

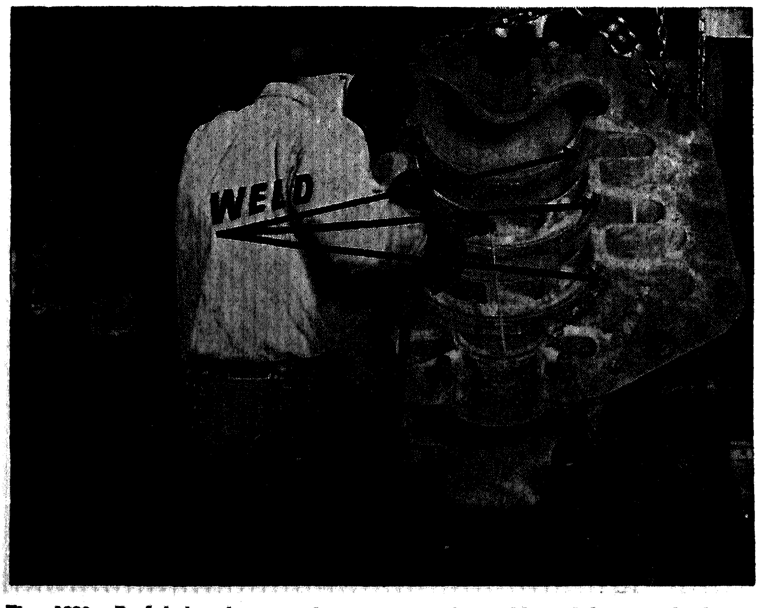


Fig. 1283. Reclaiming bronze mine pump casting with stainless steel electrode. Assures good corrosion resistance against mine water. Repair costs $150.00, saves $1650.00.

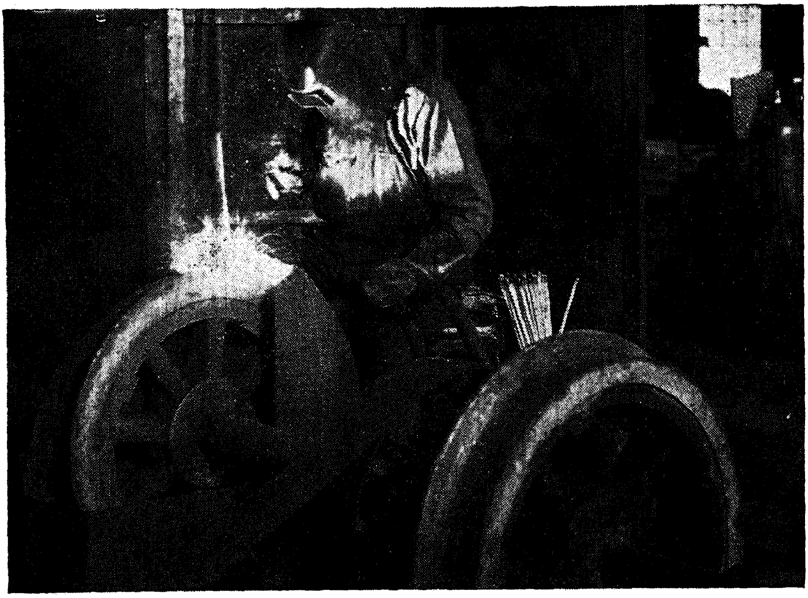


Fig. 1284. Building up worn tires of locomotive wheels with high carbon steel electrode. Retread costs $15.00 per wheel. Saves $15.00.

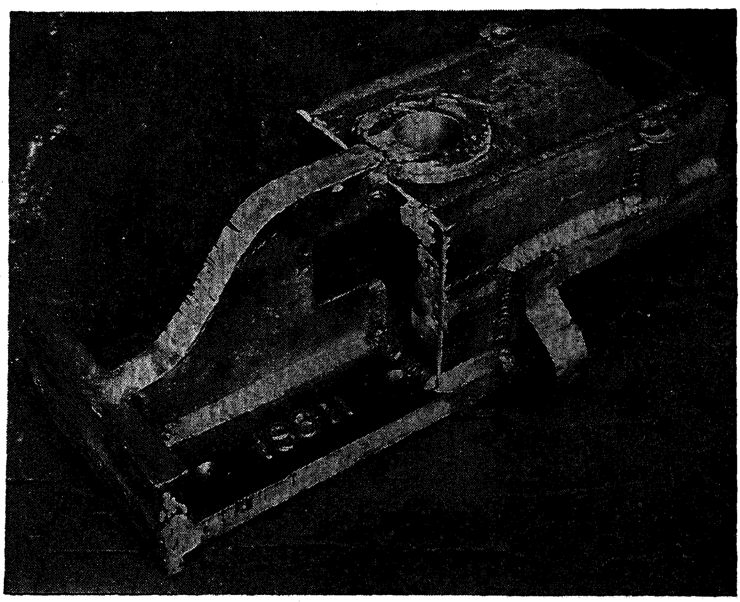


Fig. 1285. Fabricated draw head of mining locomotive. Replaces broken casting. Built in 16 hours at cost of $30.00. Saved delay of one week.

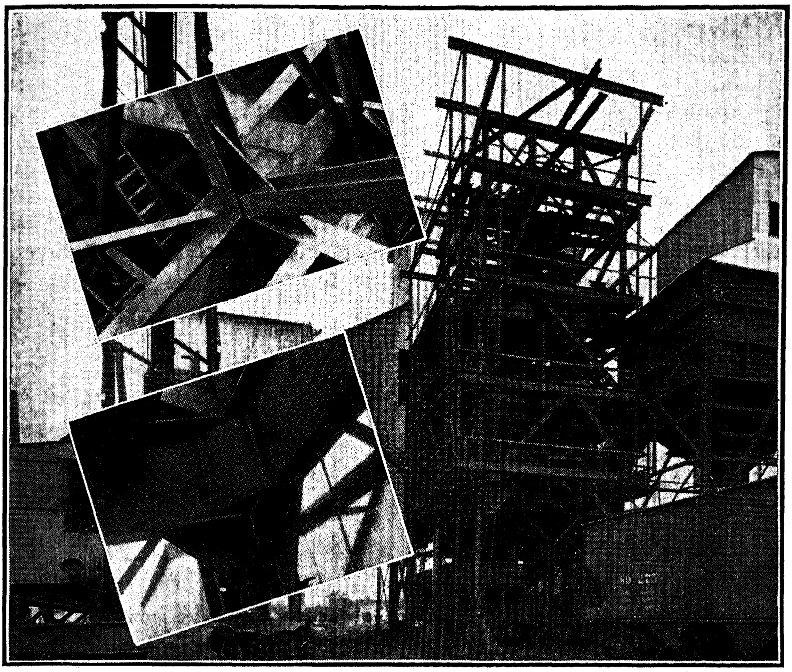


Fig. 1286. This 50-ton all-welded coal tipple structure carries four heavy duty vibrating screens. All steel was delivered direct from the mill and was flame cut and fabricated right on the erection site without detail plans. The two closeup views show connections which give the structure unusual rigidity.

Oil Production

Field Welding of Oil Well Casing.—One of the most important welding developments for the petroleum industry in recent years is in the replacement of threaded joints in the running of casing. Arc welding has already been used for this purpose in thousands of wells in California, Mid-Continent field and in the new Illinois field. Installations include one string 8100 feet long in the Mid-Continent field which was welded with beveled joints, plain end casing. When completed, pressure tests under 1200 pounds pressure proved the installation to be 100% satisfactory.

The following information is based on the experiences and procedures that have been developed during the past four or five years.

Advantages of arc welded casing include: (1) Low cost of plain end casing as compared to thread and coupled casing. (2) Elimination of leakage which is especially important for deep wells where pumping pressures are high. (3) Higher joint efficiencies (resistance to tension and collapse stresses) providing as much as 100% efficiency as compared to 50% to 70% for thread and coupled joint. (4) With butt welded joint, closer tolerances between inner and outer strings and the hole are possible, reducing cost of casing and drilling. (5) With streamlined, butt welded joints, casing is more readily recovered from an abandoned hole, offering less resistance.

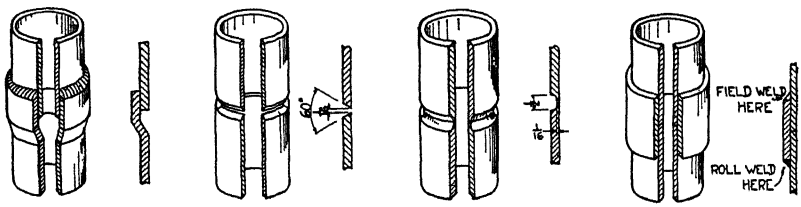


Fig. 1287 Fig. 1288 Fig. 1289

Fig. 1287. Bell and spigot type joint, used generally for surface strings in diameters of 12" to 24" and depths of 100 feet to 1200 feet.

Fig. 1288. Plain end U bevel and V bevel type joints used extensively on grades C and D casing in diameters from 5¼" to 11⅝". These types of joints have been used at setting depths up to 8160 feet.

Fig. 1289. Slip type joint, embodying a sleeve connection, is used extensively in California fields with exceptionally good speed (average of 5 minutes per joint on 11¾" casing in the case of one contractor).

Different grades of casing with different degrees of weldability (varying inversely with carbon content of the steel), are available. Grades A and B with low carbon content and tensile strengths of 55,000 to 65,000 pounds per square inch are used for short surface strings, generally with bell and spigot joints. Grades C and D, with medium carbon content (often more than .35%) and with tensile strengths of 75,000 to 95,000 pounds per square inch, are generally used with plain end V or U groove joints for deep strings. Joints of various types are shown in Figs. 1287 to 1289. Welding procedures for bell and spigot type joint and for plain end, beveled joints are given in the following tables.

Bell and Spigot Type Joint — Grades A & B Pipe

Dia. Bell Joint	Wall Thickness	1st Bead ¼" Shielded Arc Electrode Amps.	Volts	2nd Bead ¼" Shielded Arc Electrode Amps.	Volts
12"	5/16"	325	32–34	325–350	32–34
14"	⅜"	340	30–32	340–350	30–32
16"	⅜"	340	30–32	340–350	30–32
18"	⅜"	340	32–34	340–350	32–34
20"	⅜"	350	34–36	350–375	34–36
22"	⅜"	350	34–36	350–375	34–36
24"	⅜"	360	34–36	360–375	34–36

Plain End—V Bevel and U Bevel—Grades C & D Pipe

Dia. of Joint	Wall Thickness Inch	1st Bead $\frac{5}{32}''$ High Tensile Steel Electrode Amps.	Volts	2nd and 3rd Bead $\frac{3}{16}''$ High Tensile Steel Electrode Amps.	Volts
5¼″	5/16	175–185	26–28	195–210	30–32
5¾″	5/16	180–185	26–28	200–210	30–32
6″	⅜	180–185	26–28	200–215	32–34
6⅝″	⅜	185–190	28–30	215–220	32–34
7″	⅜	185–190	28–30	220–225	32–34
7⅝″	⅜	185–190	28–30	220–225	34–36
8″	⅜	190–195	30–32	225–230	34–36
8⅝″	⅜	190–210	30–32	225–230	34–36
9″	⅜	200–210	30–32	230–235	36–38
9⅝″	⅜	200–210	32–34	230–235	36–38
10″	⅜	200–210	32–34	235–240	36–38
10⅝″	⅜	200–215	32–34	235–240	38–40
11⅝″	⅜	210–215	32–34	235–240	38–40

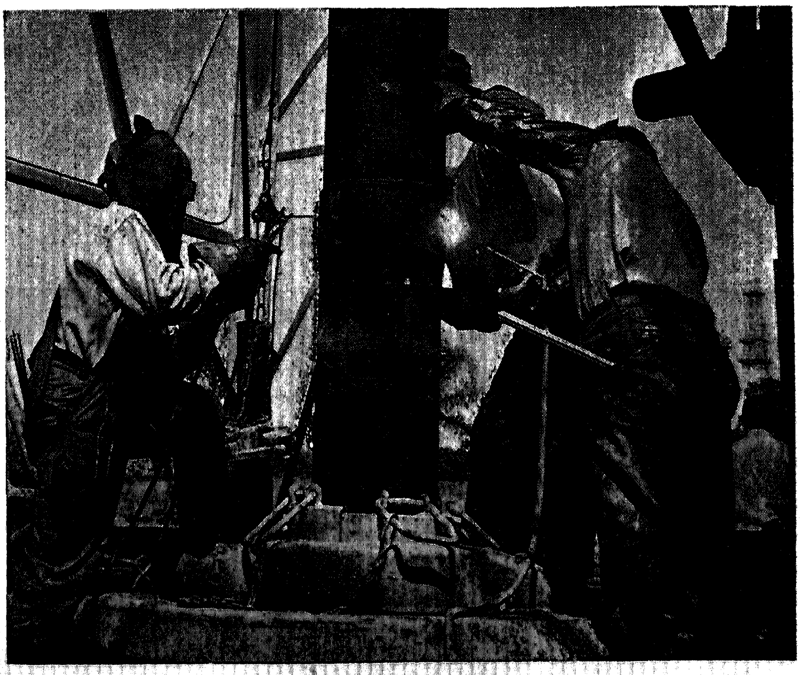


Fig. 1290. Welding 14⅝″ casing near Los Angeles, Calif. Three welders complete the bell and spigot type joint in about 5 minutes.

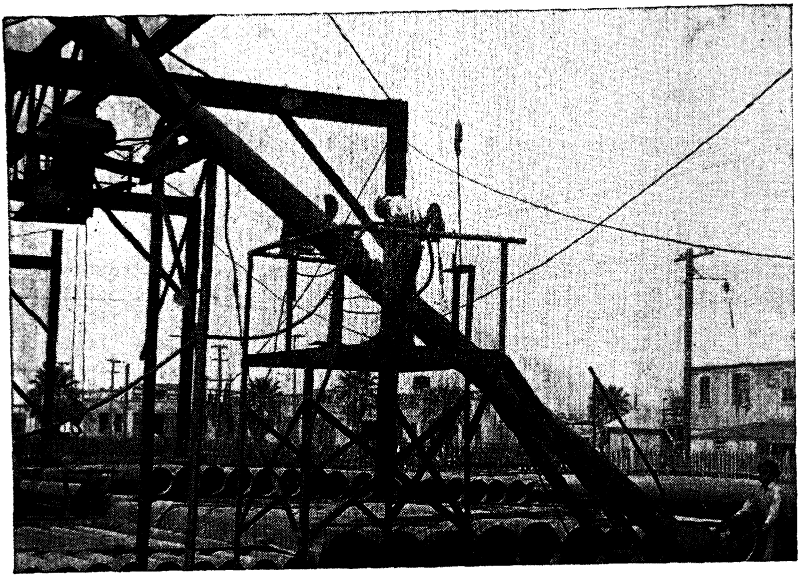


Fig. 1291. In a fabricating yard at Galveston, Texas. Joining two 16-ft. lengths of "Kaneweld" 24-inch surface casing. This casing is fabricated from rolled plate, welded longitudinally by the automatic carbon arc process. It is installed in the field in 32-ft. lengths with shielded arc mild steel electrodes.

Fig. 1292. Welded string of casing 8160 ft. long in Oklahoma field. Joints are plain end U bevel and V bevel. Three passes with 3/16" high tensile steel electrode. 100% penetration. Steps shown are: (1) Tack welding with line-up clamp in place. (2) Two welders worked simultaneously on opposite sides. (3) The completed joint.

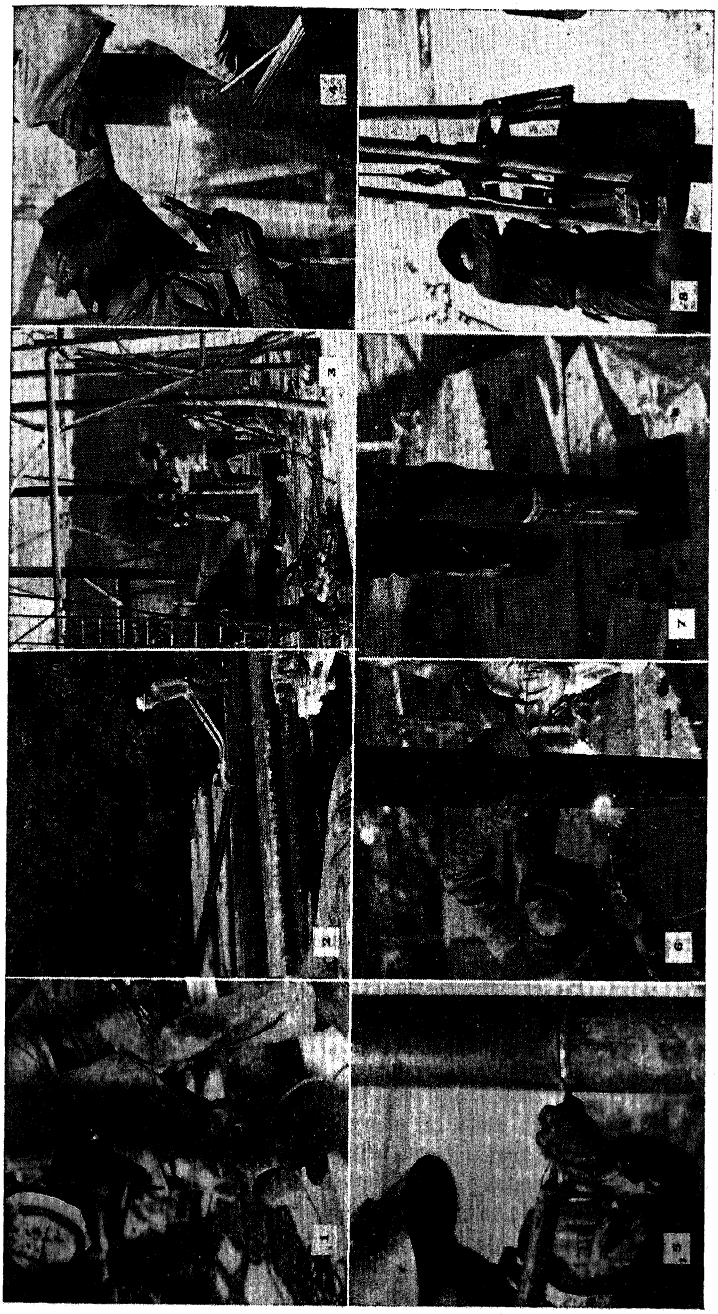


Fig. 1293. Running casing in the Illinois field. 1585 ft. well. 6-inch o.d. casing. Joints are plain end, U bevel. Two passes made with 3/16" mild steel shielded arc electrode. Eight steps shown are: (1) Applying lifting clamp. (2) Going up. (3) Lined up by clamp, tack welding. (4) Welding first bead. (5) Removing weld slag. (6) Welding second bead. (7) Slips removed. Going down another 40 feet. (8) Slips applied. Elevator released. Ready for another joint. . . . Total time 3 minutes 30 seconds.

Fig. 1294. Pumping unit of all welded steel construction in the East Texas field. Welded construction is used almost exclusively for equipment of this type to assure maximum rigidity and minimum weight for lowest manufacturing and operating costs.

Welding of Tool Joints.—After drill pipe has been used for some time, the joints become loose and weakened due to the whipping action that takes place during drilling.

Especially in deep well operations, this condition of looseness at the joints is the concern of drillers because it results in leakage of mud pump pressure which should be maintained for most economical and speedy drilling. Moreover, it is sometimes dangerous, since failure of a joint (it usually twists off at last engaged thread) would result in the dropping of the string and the waste of considerable time and money for fishing out operations.

It is to overcome these conditions that many producers are welding the tool joints at both ends of every section of pipe. This makes possible a construction that is permanently strong and tight at the joint, making possible higher mud pump pressures at the bit, for faster drilling, and precluding twist offs at the last threads where they normally occur. Also, because the joints are permanently rigid, there is less whipping action, resulting in a straighter, more uniform hole which costs less to cement.

Standard A.P.I. Joints.—Following is the procedure used by a tool company in the North Texas Field in the welding of drill pipe joints:

1. Both the pin end (male joint) and box end (female joint) are tightened in a lathe under 15,000 foot pounds. This assures a tight seating of the threads so as to secure their maximum strength. (Some producers who weld their joints in the field and do not have the necessary equipment for tightening the joints eliminate these operations.)

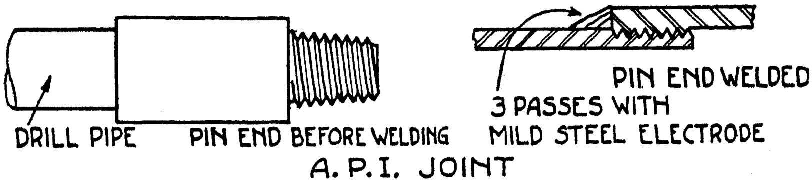


Fig. 1295. A.P.I. joint. Pin end. Before and after welding.

2. Pin end. It is shown in the sketch above. The coupling is welded to the pipe with ¼″ Type A shielded arc electrode. This is a roll welding operation with the welding operator doing the rolling with his left hand. Both ends of the pipe are mounted on rollers to facilitate turning and the pipe is turned by the welder with a standard pipe turner with a handle about two feet long. Three passes are made, producing a bead which slopes down from the top of the coupling shoulder to the pipe at an angle of about 30 degrees. See Fig. 1295.

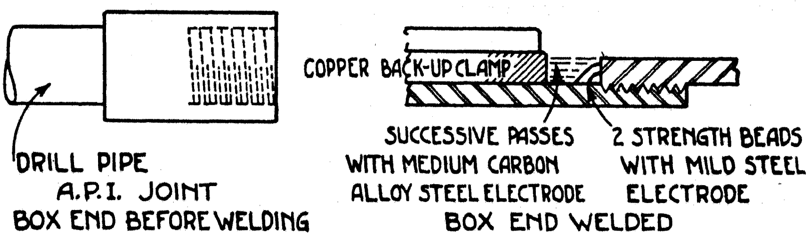


Fig. 1296. A.P.I. joint. Box end. Before and after welding.

3. Box end. It is shown in Fig. 1296. Two beads are first made with Type A shielded arc electrode for strength purposes. A copper back-up clamp is then used to apply a wear-resisting shoulder with a flat face up to the level of the joint. This weld, made with a medium carbon alloy steel electrode, provides a hard, flat surface which is desirable at this point because this is the point of contact with the elevator and is therefore the surface that must bear the entire load of the string below it, (when pulling out of hole). The back-up clamp is positioned between the clamp and the joint is filled up to the edge of the joint with medium carbon alloy steel electrode. This is a roll welding operation, the rolling performed by the welder.

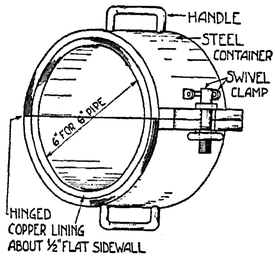


Fig. 1297. Copper back-up clamp for welding box end.

The copper back-up clamp used for this operation is designed as shown in Fig. 1297.

Note: Instead of a medium carbon alloy steel electrode, some operators use a high carbon steel electrode for the final passes on the box end.

Hydril Externally Upset Drill Pipe Joint.—A cut-away view of this type of joint is shown in Fig. 1298. Due to the upset section, this pipe is said to be the strongest drill pipe available, providing extra thickness of metal at the threads.

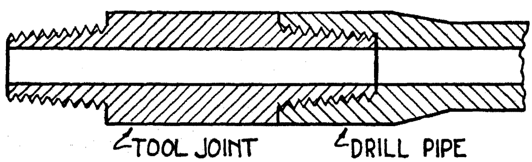


Fig. 1298. Hydril externally up-set joint.

Constant rotation in drilling naturally wears down the outside diameter of the tool joint as well as the outside diameter of the drill pipe along the up-set portion. Since it is desirable to maintain the full section at the joint for maximum strength, the worn joint is reclaimed by arc welding, using the following procedure.

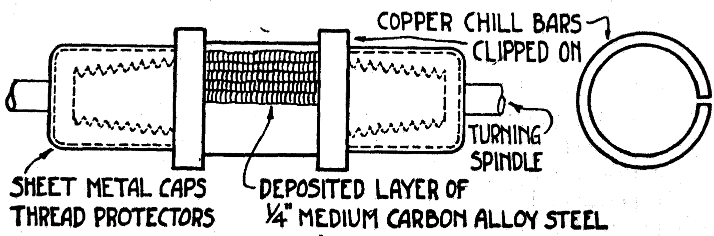


Fig. 1299. Set-up for building up worn hydril tool joint.

The joint itself is mounted on turning spindles as shown in Fig. 1299. The threads should be protected from spatter by a sheet metal cap designed to fit over them as shown. Copper chill bars should be used, positioned as shown at the ends of the joint. These chill bars help to absorb the welding heat from the tool joint and maintain original machined dimensions.

The most effective electrode has been found to be 1/4″ medium carbon alloy steel applied in longitudinal beads with 250 amperes. A single layer of the beads is applied all around the joint.

To build up the externally up-set section of the pipe *it is important that the tool joint be inserted* before welding in order to prevent undue contraction of the threads and to preclude remachining.

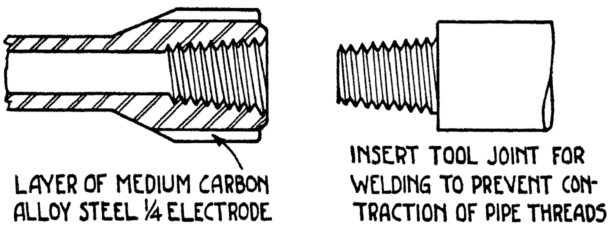


Fig. 1300. Set-up for building up worn hydril drill pipe—first method.

The pipe can be mounted on rollers to facilitate turning. A single layer of beads run longitudinally with 1/4″ medium carbon alloy steel electrode is recommended. Refer to Fig. 1300.

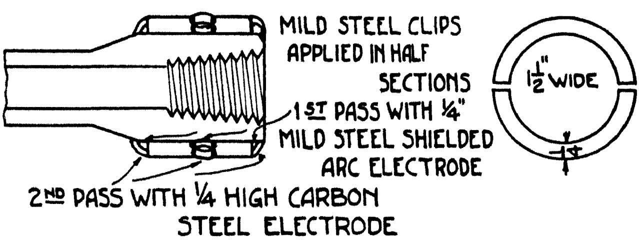


Fig. 1301. Second method for building-up worn externally up-set hydril drill pipe.

Another method that has been found successful in building up the drill pipe is as illustrated in Fig. 1301. By this method, mild steel clips approximately 1/4″ x 1 1/2″ are welded to the pipe in order to build up the surface. The first pass, joining the clips to the pipe, is made with 1/4″ shielded arc mild steel electrode. A second pass of 1/4″ high carbon steel electrode is then applied, making a flush joint but not overflush. In cases where the diameter of the pipe after completion must be exact, the drill pipe is machined to the proper size before welding.

Fig. 1302. Welding pin end of standard A.P.I. joint. Left below: Completed pin end joints. Right below: Completed box end joints.

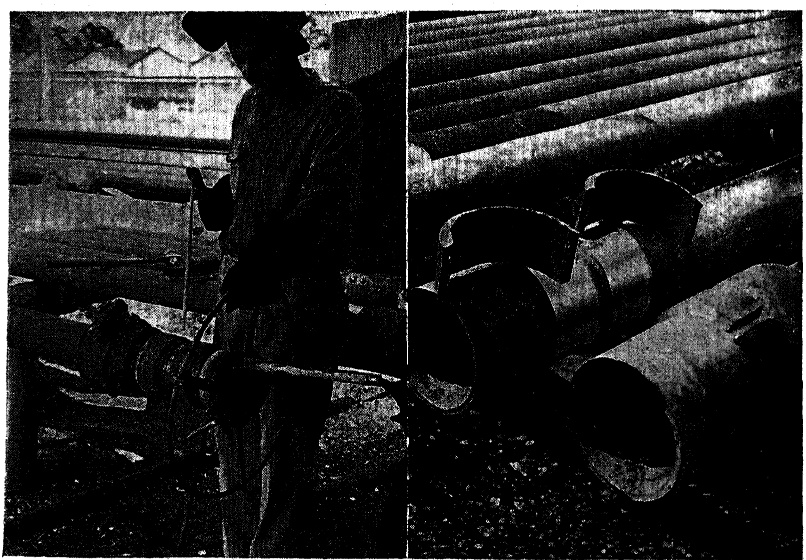


Fig. 1303. Two steps showing another method of building up box ends of A.P.I. joints. Joints are machined about 1/8" to receive semi-circular medium-carbon steel clips as shown. Edges of clips are scarfed for maximum weld penetration. Initial passes are made with 5/16" mild steel shielded arc electrode. Finish passes are made with medium carbon alloy steel electrode for resistance to impact and abrasion. Note copper back-up clamp on left and turning device on right.

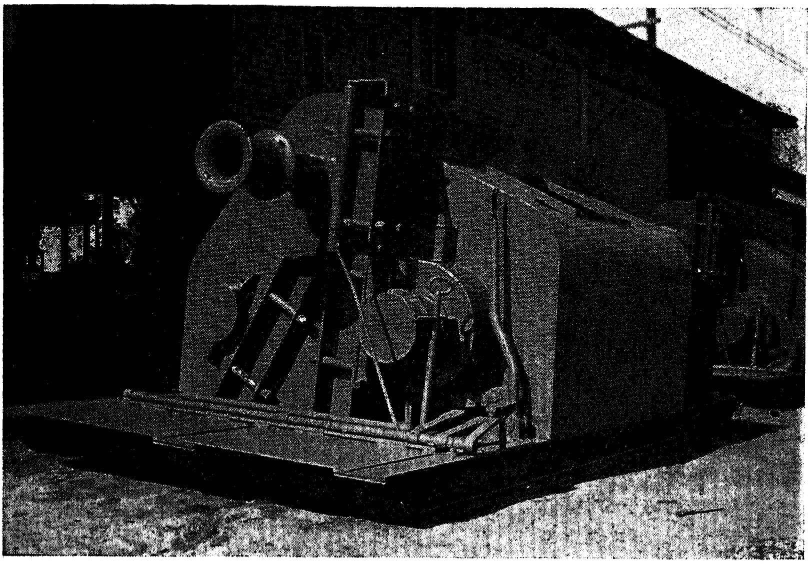


Fig. 1304. All welded steel unitized draw-works of 8-inch capacity. Welded fabrication is used almost 100%. Even the drum is of this construction. (See Fig. 1276.)

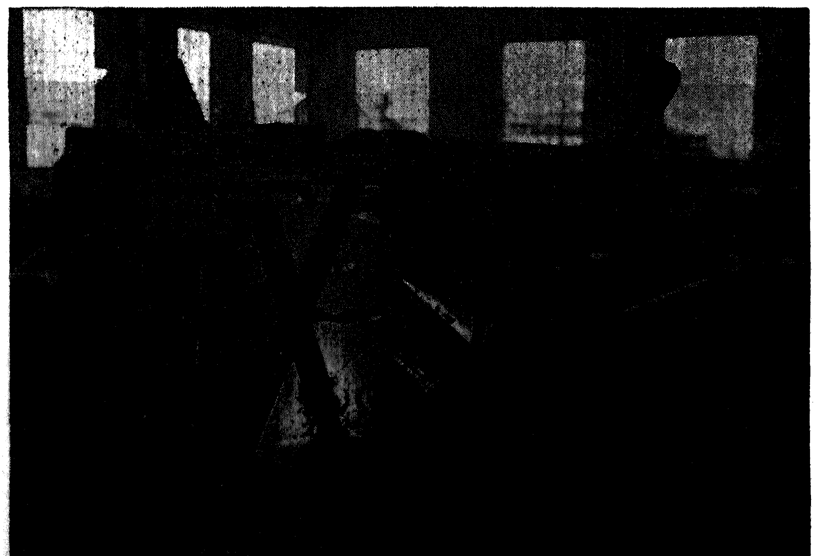


Fig. 1305. Fabricating a telescoping type double leg 60-ft. mast for a portable core drilling rig. The rig is designed to drill to a depth of 5000 ft. with 3-in. drill pipe, and is capable of handling 120,000 lbs.

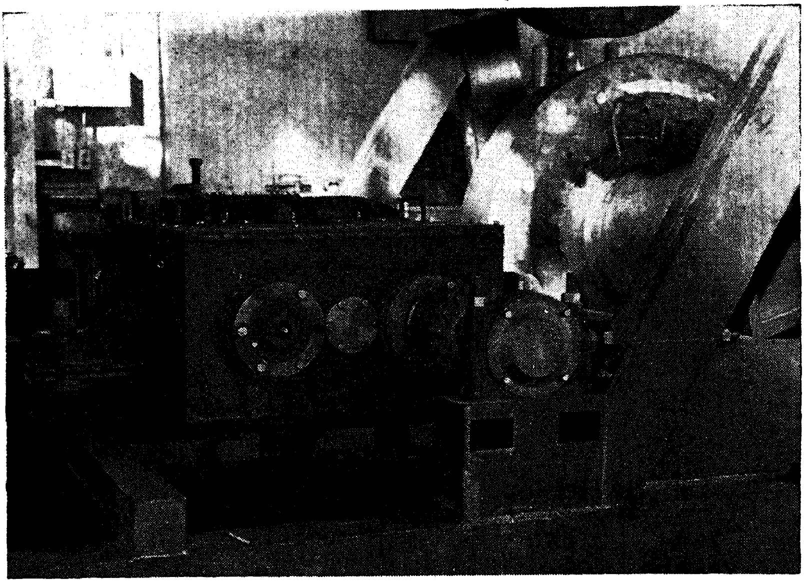


Fig. 1306. Close-up of a welded steel rotary draw-works showing speed reducer and other interesting design details.

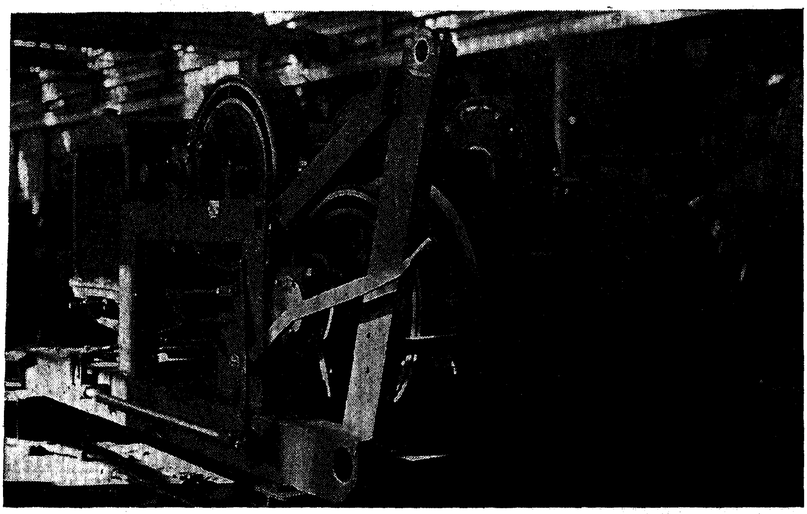


Fig. 1307. Rotary draw-works of welded steel construction in the course of manufacture.

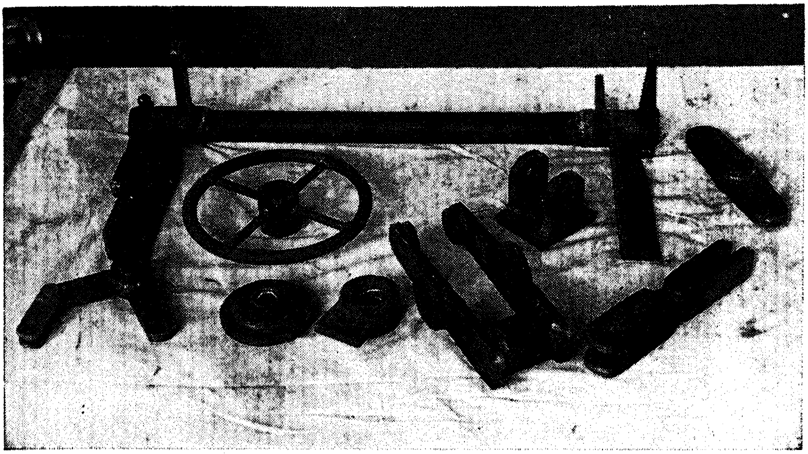


Fig. 1308. A few miscellaneous welded parts used in the construction of the draw-works shown in Fig. 1307.

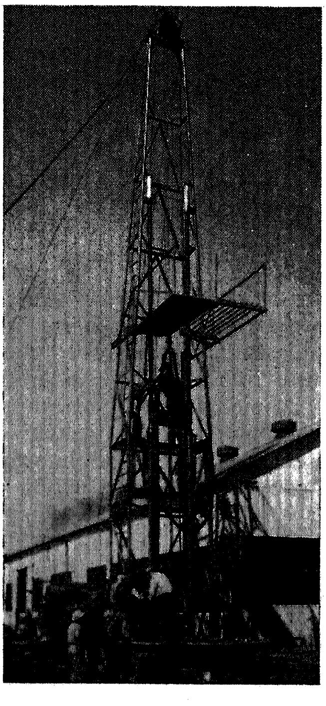


Fig. 1309. All welded portable drilling rig showing interesting design details. This rig is mounted on a special truck for use in mountainous country. It embodies hydraulic ram to force pressure on drill stem for faster drilling. When rig is disassembled it folds into one-third the operating length. See Fig. 570 for closeup of joints.

Fig. 1310. Oil well reamers and mills. Built from mild steel stock with a build-up of tool steel by arc welding. Worn reamers are hard-faced by the same method.

Oil Refineries

Arc welded construction of cracking stills, fractionating towers, piping, evaporators, cooling boxes, condensers and other refining equipment has made possible radically improved refining processes resulting in greatly decreased costs of petroleum products and conservation of oil resources. It is claimed that welded construction of the modern refinery makes possible twice as many gallons of gasoline per barrel of crude oil and has cut the cost of gasoline five cents per gallon as compared to the old conventional construction.

Several recent refinery installations are illustrated on the following pages.

Also see the section on Tanks.

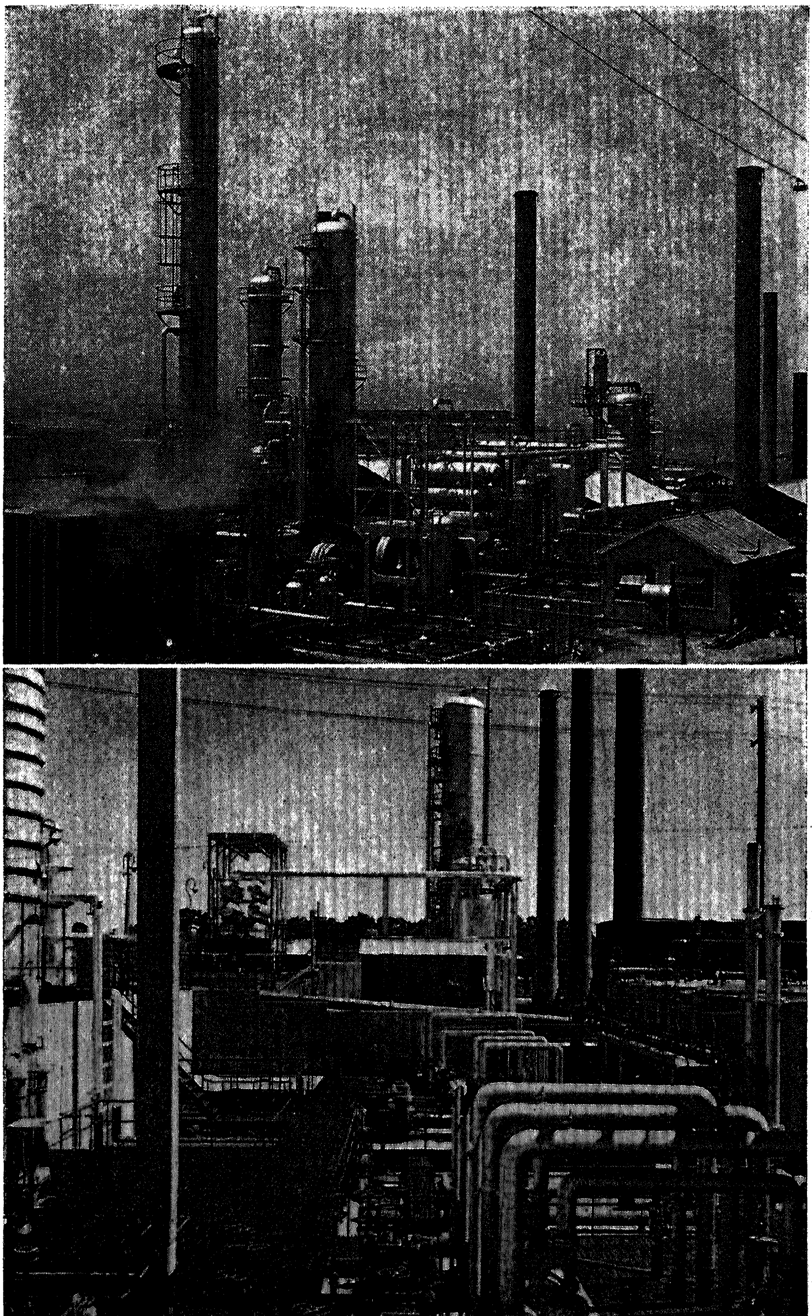


Fig. 1311. A new $2,000,000 refinery at Oleum, Calif. Arc welding was used extensively in the fabrication and erection of this modern plant.

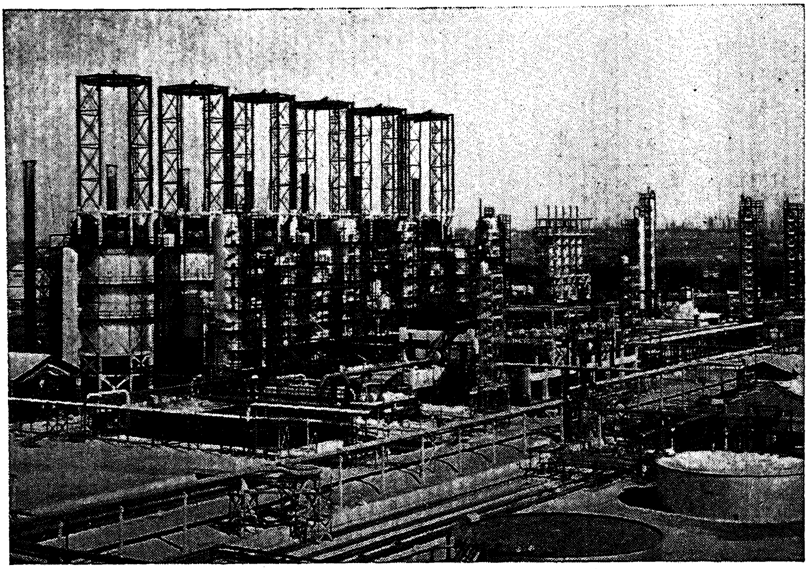


Fig. 1312. General view of new $5,000,000 refinery at Watson, Calif. Fractionating towers, 5000 pre-fabricated piped spools and other parts of this plant include about thirty miles of welded joints made with five carloads of shielded arc mild steel electrodes. Storage tanks too are of arc welded construction. See Fig. 1511.

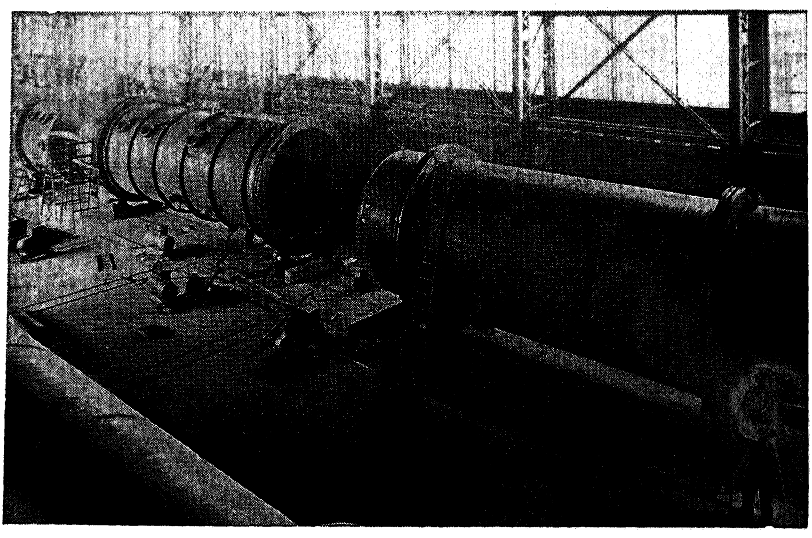


Fig. 1313. Shop view showing the fabrication of fractionating towers for the refinery illustrated in Fig. 1312.

Ornamental Iron Work

Ornamental Iron.—Skill and artistry so essential in ornamental iron work are aptly aided by the use of the electric arc welding process. In many designs the desired rustic effect can be obtained by fabricating the work with the electric arc and leaving the welds in their natural state without filing or finishing. The maximum strength is also acquired by use of this construction. Examples of this type of work are shown in the following illustrations.

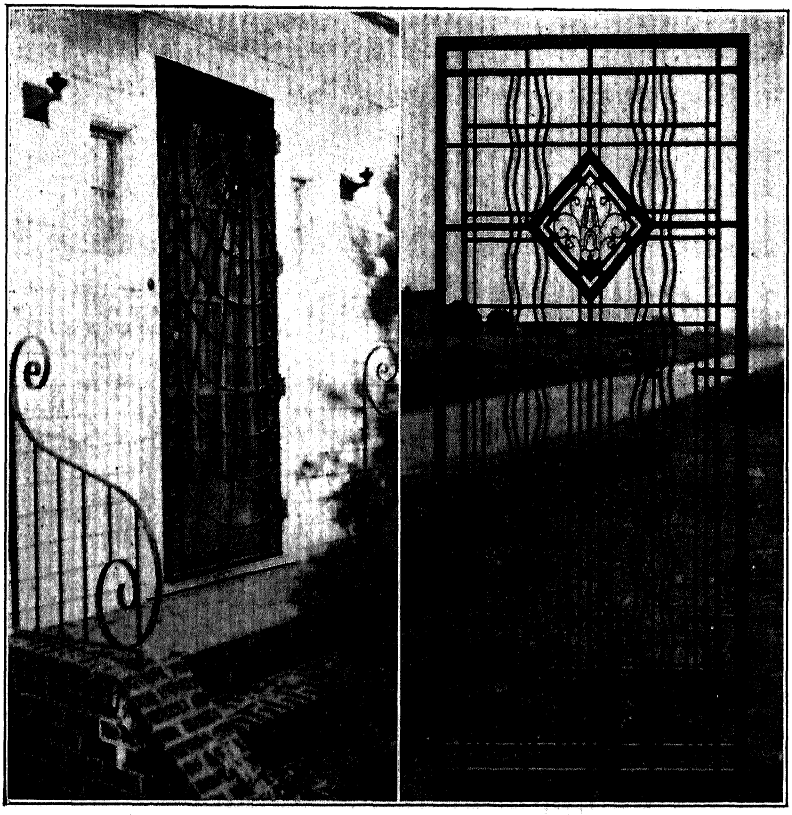


Fig. 1314. Frame works for door and screens fabricated from bar stock by arc welding.

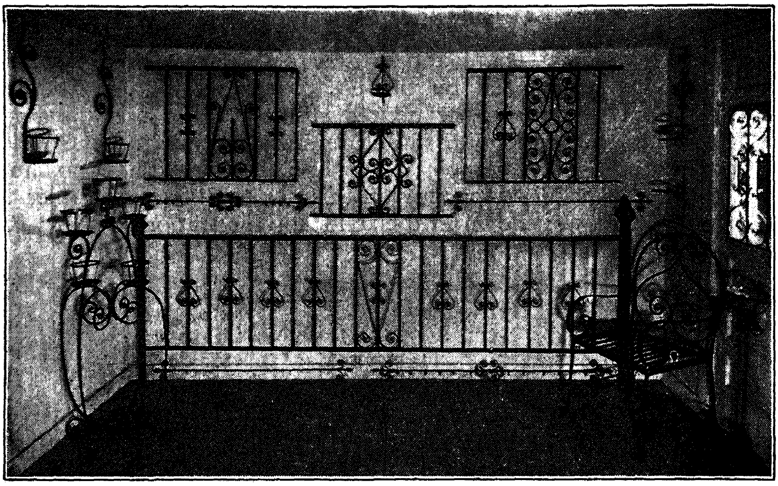


Fig. 1315. A few typical examples of ornamental iron work fabricated by arc welding.

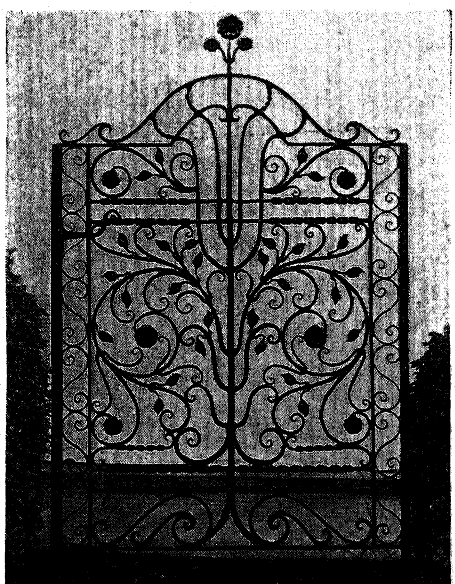


Fig. 1316. The 108 welds required in the assembly of this garden gate were made by one man in seven hours. No bolts or rivets are used.

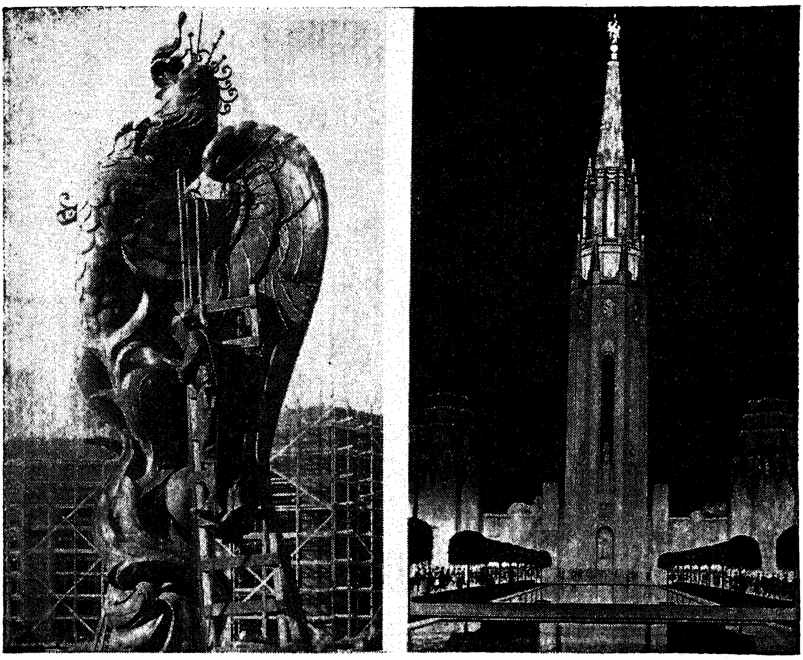


Fig. 1317. Ornamental symbol used on top of main building at Golden Gate International Exposition. This Phoenix is 22 ft. high, weighs 5000 lbs., and comprises 700 separate hand-shaped 16-gauge metal sections fused together by 6800 lineal feet of arc welding.

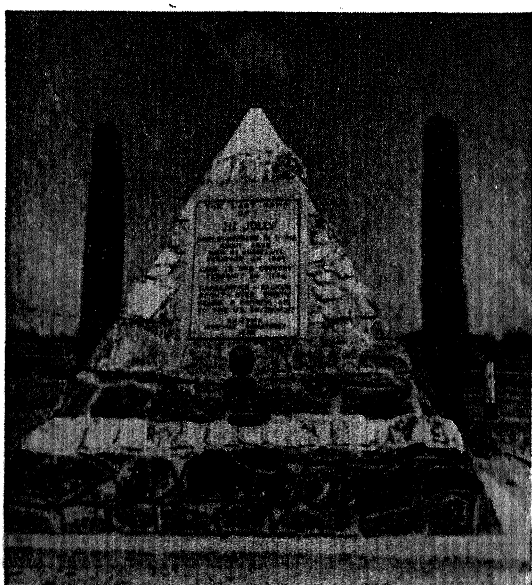


Fig. 1318. Lettering for this memorial was made with metal applied by electric arc process.

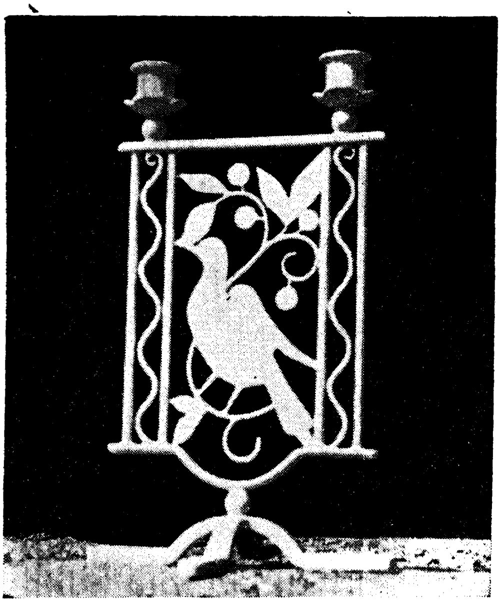


Fig. 1319. Candlestick, fabricated from mild steel by arc welding. 12" high. Contains more than 50 welds.

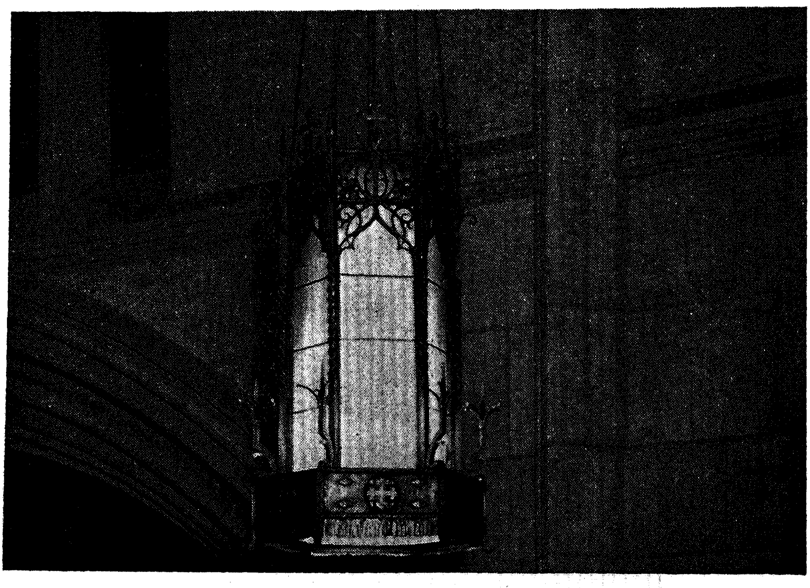


Fig. 1320. Lighting fixture fabricated by arc welding, saving $40 each. Approximately 3 ft. high.

Pipe Fabrication

Large diameter pipe is usually fabricated by the automatic shielded carbon arc. Diameter sizes range from 12 inches to 90 inches and larger. The wall thickness varies in accordance with diameter, size and service requirements of the pipe. The plates are formed so that there are one or more longitudinal seams in the pipe, depending upon its diameter, size and forming equipment available. The longitudinal seams are butt joints. The formed plate for the smaller sizes of pipe is generally placed over a mandrel with the abutting edges of the plate clamped securely in place for welding. An automatic welding head mounted on a beam riding carriage travels over the butt joint, welding as it goes. For procedure, see Pages 241 to 249.

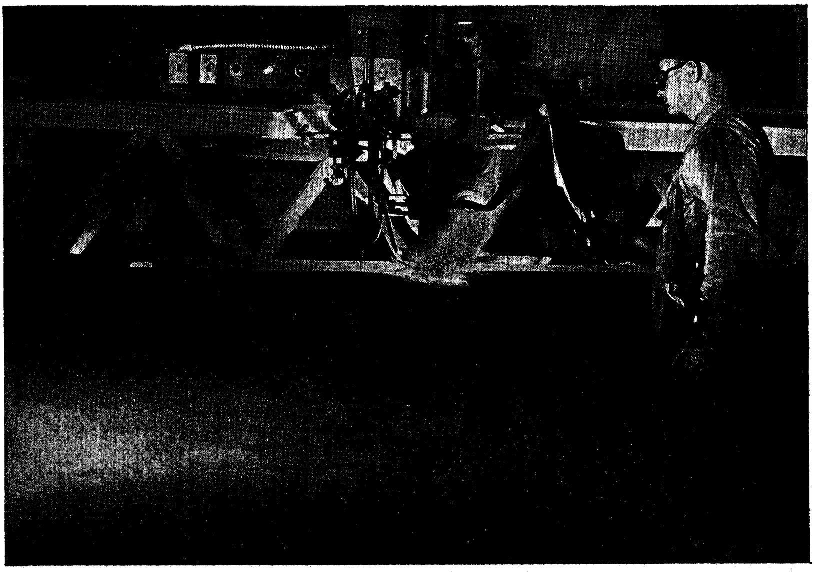


Fig. 1321. Welding 51-inch pipe in 30 ft. sections made from two rolled plates of ⅜-in. thickness by the automatic shielded carbon arc process.

Longitudinal seams in pipe larger than 30 inches in diameter such as used in water lines are usually welded inside and outside. A typical application, that for a 51-inch pipe used in construction of a feeder line in the Colorado River aqueduct system, is shown in Figs. 1321 and 1322. It is being welded from two ⅜-inch rolled-plates in 30-foot lengths. No plate preparation is necessary. The rolled semi-circular plates are fitted together in a jig and are tack welded. One seam is then finish welded on the outside with an automatic shielded carbon arc welder which travels on a beam as shown in Fig. 1321. It is then rotated 180 degrees and the other outside seam is welded.

The 30-foot section is then moved to the set-up shown in Fig. 1322 and the inside seams are welded with a tractor type automatic shielded carbon arc welder. The inside passes are made flush with the pipe, avoiding the necessity for chipping.

Welding from both sides in this manner produces a joint that neutralizes stresses.

One end of the 30-foot sections is expanded to provide a bell and spigot circumferential joint which is field welded on the inside and the outside. See Fig. 1355.

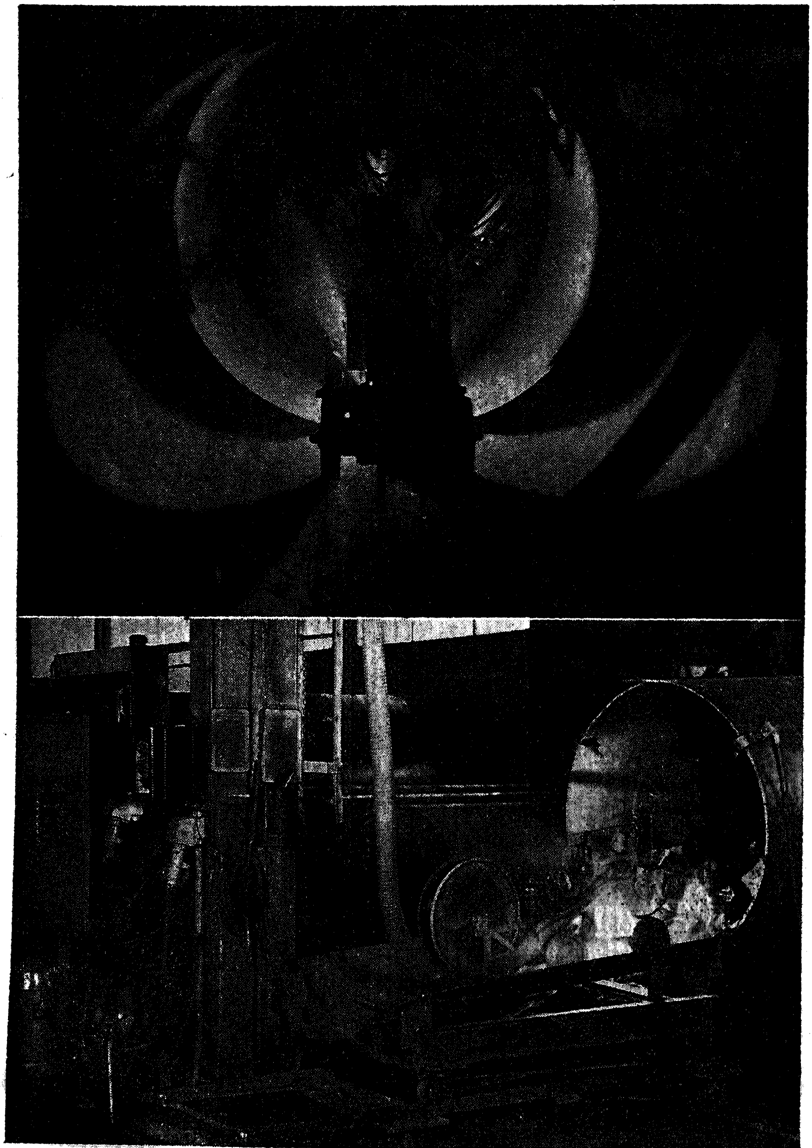


Fig. 1322. Tractor type automatic shielded carbon arc welder welding the inside seams of 51-inch pipe.

Plain butt joints up to $\frac{3}{8}$-inch thickness are welded with complete penetration from one side only The welding of 16-inch diameter pipe at 40 feet per hour is illustrated in Fig. 1323.

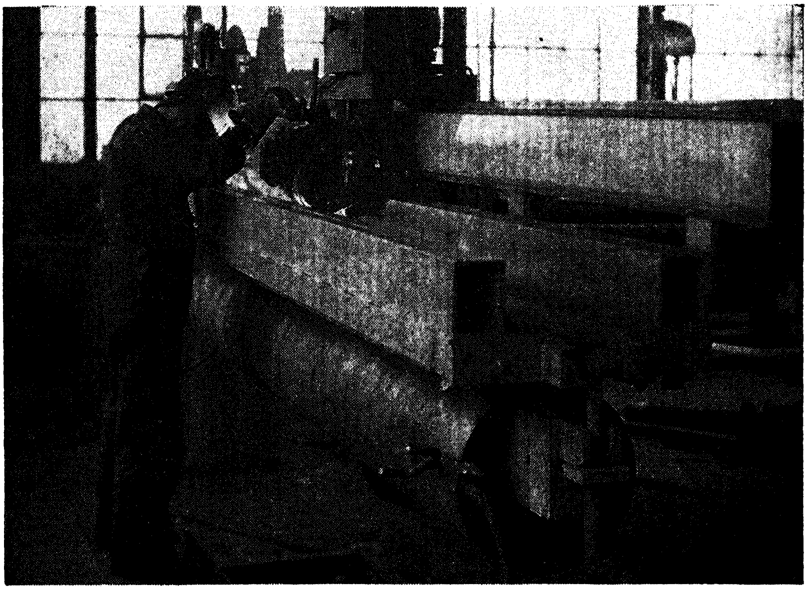


Fig. 1323. Welding 16-inch diameter pipe with the automatic shielded carbon arc process. Complete penetration is obtained by welding from one side as shown.

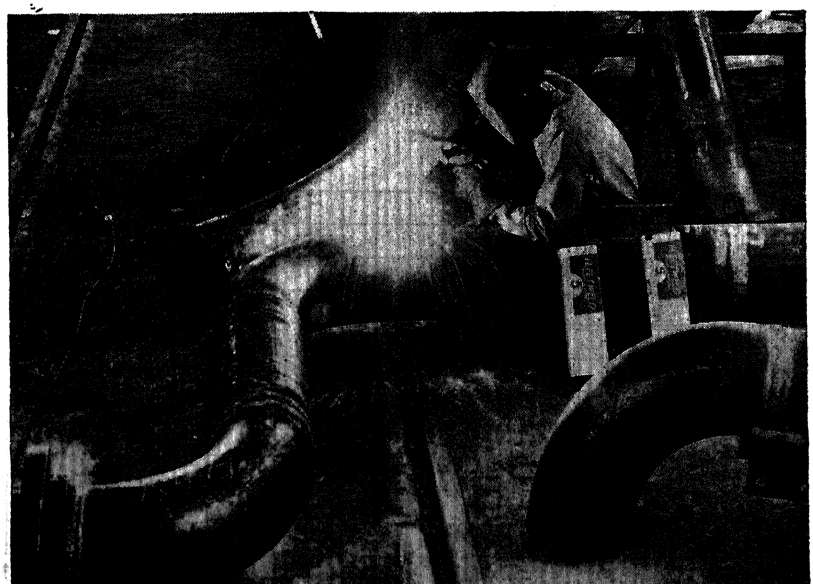


Fig. 1324. Fabricating complicated turns for a water supply system by manual shielded arc welding in a large mid-western pipe company.

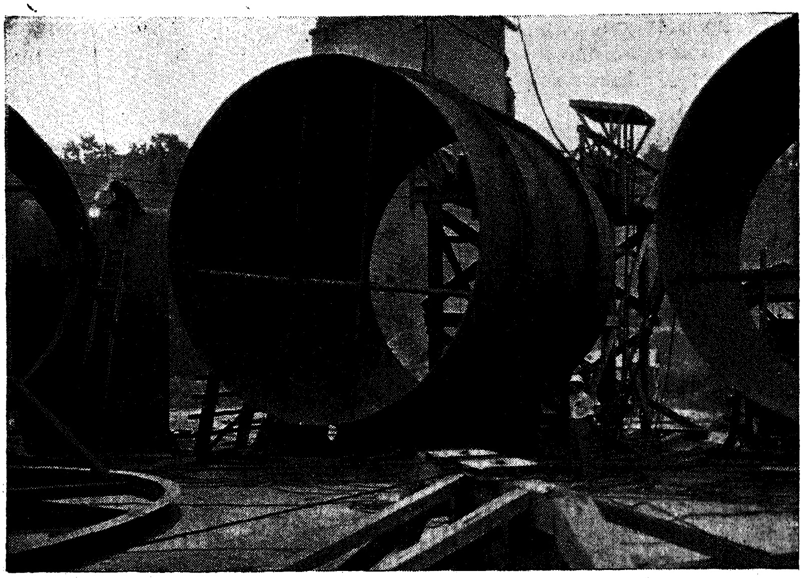


Fig. 1325. Sections of 20-foot diameter penstock fabricated by automatic shielded carbon arc welding in the field.

Pipe Lines (Oil and Gas)

The simplicity, speed and high quality of shielded arc welding has resulted in wide-spread progress in the construction of cross-country pipe lines during the past ten years.

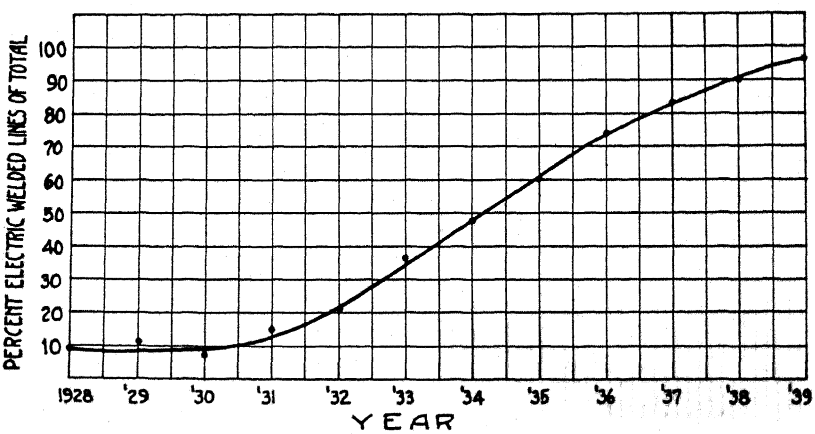


Fig. 1326. Chart showing increasing demand for arc welded pipe lines.

The chart shown in Fig. 1326, plotted from data secured from a source which is considered authoritative, shows how the demand for shielded arc welding in pipe line construction is growing.

Various types of joints employed in pipe line welding are illustrated in Figs. 1327 to 1330. The plain end joint shown in Fig. 1330 was introduced in 1933 for oil line construction. Up until 1938 it was used only on lines as large as 12 inches. However, due to proven economies and highly satisfactory service of more than one million shielded arc welded joints in service, this simple type of joint has now been extended to pipe as large as 16-inch diameter. Resultant economies in construction and operation of oil lines are apparent.

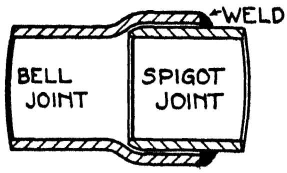


Fig. 1327. Bell and spigot type joint, used back in the days of the unshielded arc.

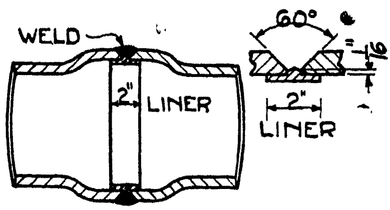


Fig. 1328. Double bell joint with liner for oil lines. Built between 1930 and 1933.

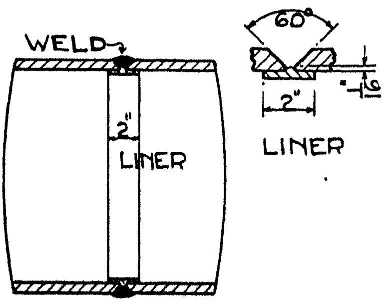


Fig. 1329. Plain end joint with liner, used for gas lines as large as 24 in. Two welding beads are required.

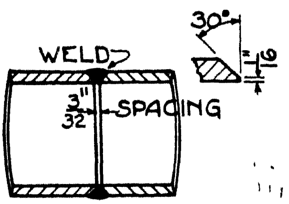


Fig. 1330. Plain end joint without liner, now used extensively for oil lines as large as 12 in. Three beads are required.

The plain end joint with liner is used almost exclusively for gas lines because the resistance to flow caused by the liner is negligible and because this type of joint in larger size pipes is most economical.

Following is a general description of modern practice in the construction of oil and gas lines, using the plain end joint with liner for gas lines, and the plain end joint without liner for oil lines.

Out in front of the entire construction gang goes the lineup and tacking crew. Aided by a tractor and hoist, they put the pipe lengths on ball-bearing dollies for rolling. The tack welder tacks the adjacent lengths of pipe together usually at four points in the circumference. He joins as many lengths as the nature of the line and the contour of the country will permit. The long tack-welded section is then left on the dollies ready for the firing line welders who follow close behind

Fig. 1331. This 10-in. arc welded oil line, 304 miles long, was built in a record time of 70 days. Every joint was skillfully tested under air pressure with soap suds and not a single leak was found in the entire line. Joints are plain end without liner.

Fig. 1332. Tack welding with the shielded arc during the lining-up operations of the world's longest welded pipe line which is located in Iraq.

The firing line crew, including several welders, completes the welds of the long sections. These operators weld at the top of the pipe while a helper turns the pipe by means of a chain pipe wrench. Thus, all welding is done in a flat, downhand position, and by using large-size electrodes ($\frac{1}{4}''$, $\frac{5}{16}''$ and sometimes $\frac{3}{8}''$) and heavy welding current, high welding speeds are obtained. After completion of each bead, a helper cleans all of the slag from the weld. Each completed weld is inspected for any imperfections before the welder proceeds to the next joint. When the section is entirely welded, the pipe is rolled off the dollies and the pipe sections are painted and then joined into a continuous stretch by "bell-hole" welding.

This pipe is placed on timber skids near or over the trench and, in this position, it is "bell-hole" welded. Here, instead of having the pipe rolled beneath the arc, the operator plies the arc around the pipe. For these welds, he uses smaller sized electrodes ($\frac{5}{32}''$ or $\frac{3}{16}''$) with 100 to 200 amperes.

In the construction of oil and gas lines in rough terrain or very muddy or sandy country, the "stove-pipe" method is frequently employed. Here, all joints (usually plain end without liner) are position-welded like bell-hole joints. One joint at a time is added to the line, making it possible to reduce the size of the crew and amount of equipment, and keep operations bunched together under one supervisor. During alignment and tacking, the joint is usually held in place by a line-up clamp or "grasshopper." After tacking, two bell-hole welders work simultaneously on both sides of the joint, making the complete first bead, each welder coming down from the top. This type of construction is illustrated in Fig. 1334.

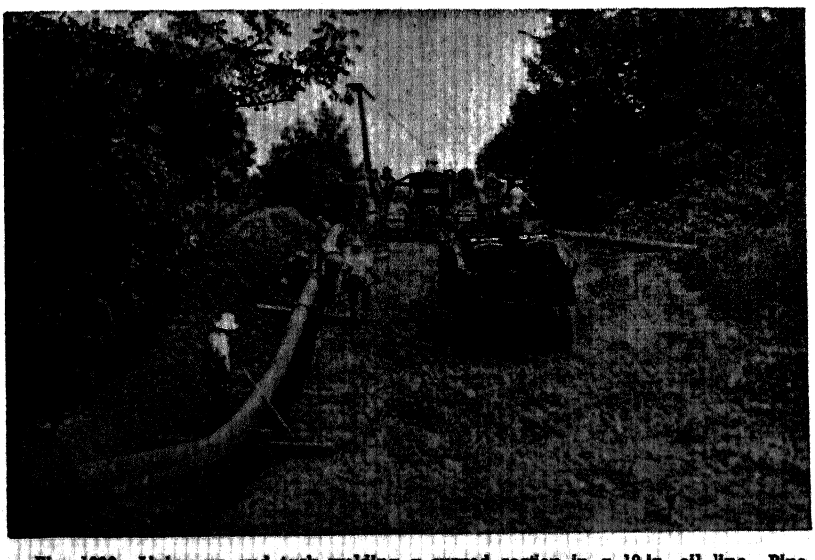


Fig. 1333. Lining up and tack welding a curved section in a 10-in. oil line. Pipe bends such as shown are usually made in the field by heating the pipe with kerosene burners and applying force through a jack built of pipe by means of a tractor.

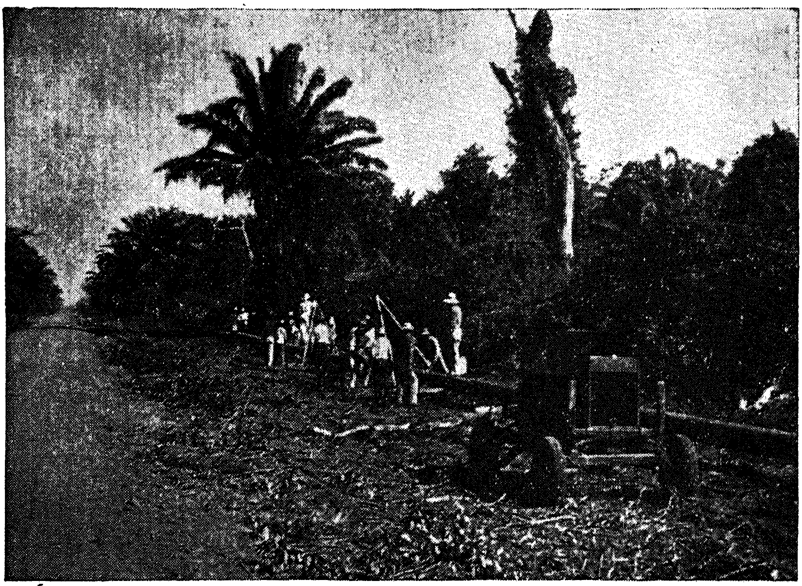


Fig. 1334. Welding a 12-in. line in Colombia by the stove-pipe method.

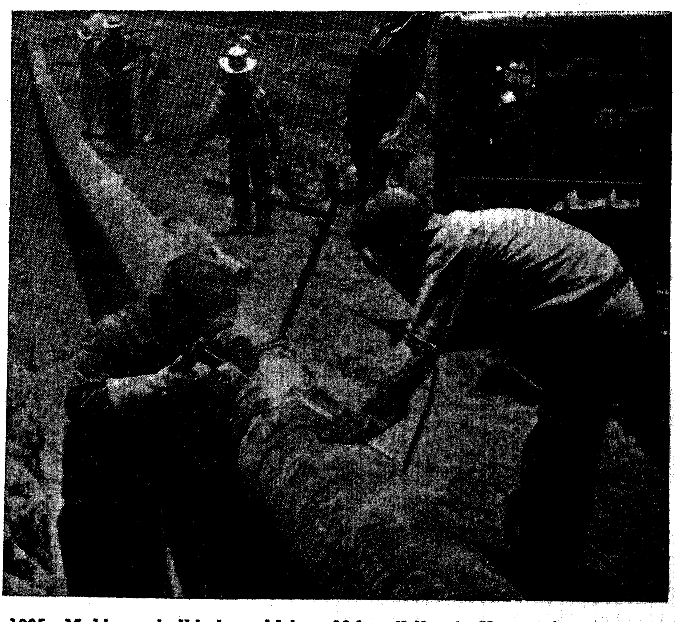


Fig. 1335. Making a bell-hole weld in a 16-in. oil line in Venezuela. Two tie-in gangs (two tackers and four welders) joined the roll welded sections, making a total of 2800 bell-hole welds with 3/16-in. Type A shielded arc electrodes. Two welders often worked simultaneously at each bell-hole weld as shown.

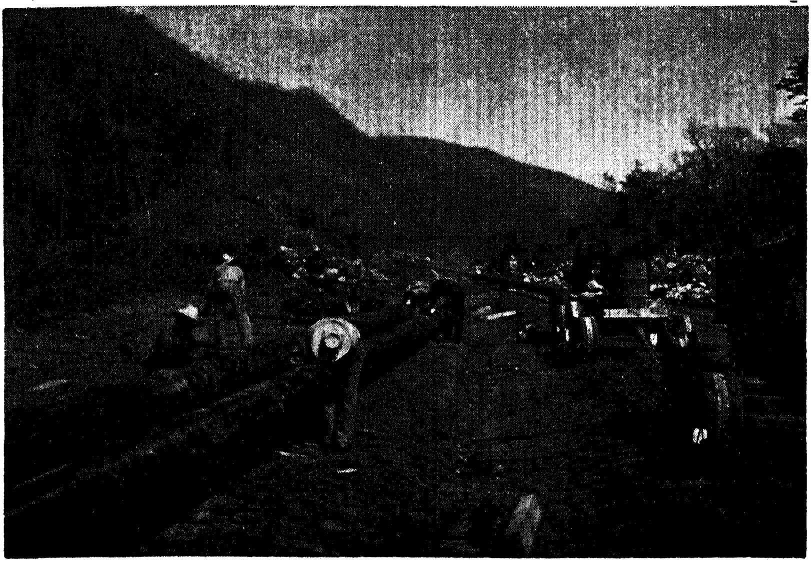


Fig. 1336. A firing line gang on a 16-in. oil line in Venezuela. Gang consisted of one tacker and five welders. Joints are V-groove butt joints without liner. First pass made with 3/16-in., second pass with ¼-in., third pass with 5/16-in. Type A shielded arc electrode.

Fig. 1337. Making bell-hole weld in a 16-in. oil line in Missouri. Construction of this 16-in. oil line (plain butt joints without back-up ring) made it possible to use one pipe line in place of several smaller lines.

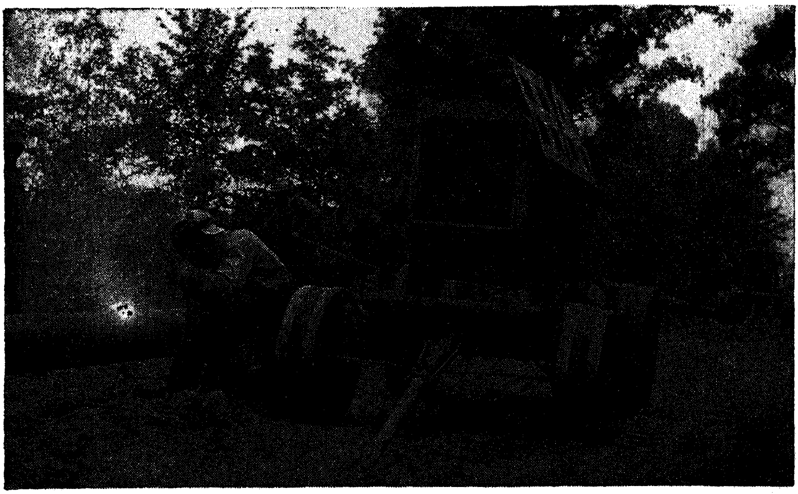


Fig. 1338. Making a firing line weld in a 10-in. oil line in Illinois. This is one section of a 357-mile line, all shielded arc welded.

Fig. 1338-A. In a flat lay of land, the firing line gang roll-welds sections of pipe for a 10-inch oil line in Illinois traversing hilly country.

The wall thickness of the pipe for river crossings is generally 50% to 100% greater than that used in the rest of the line. The pipe is roll-welded and bell-hole welded into a section long enough to cross the river. Each joint is usually reinforced by a welded-on sleeve such as those shown in Fig. 1349. Special river clamps, four to ten feet long and weighing 1000 to 3000 lbs. each are often bolted to the pipe at intervals, serving as a means of anchoring. The pipe section is then attached by cable to tractors and pulled onto pontoons from which it is guided by stakes into a dredged out ditch in the river bottom. It is usually buried at a minimum depth of eight feet.

Fig. 1339. Building a 4-in. oil feeder line in the Illinois field. This was welded by the stove-pipe method. Left: Line-up clamp brings the ends of the pipe together for tack welding. Right: Completing the weld — made with three passes of 3/16-in. Type A shielded arc electrode.

TABLE I—ELECTRODE SIZES

Size Pipe	Stringer Bead	Second Bead	Third Bead
ROLL WELDING WITHOUT BACKING-UP RING			
4"	5/32"	3/16"	1/4"
6"	5/32"	1/4"	1/4" or 5/16"
8"	5/32" or 3/16"	1/4"	1/4" or 5/16"
10"	5/32" or 3/16"	1/4"	1/4" or 5/16"
12"	5/32" or 3/16"	1/4"	5/16" or 3/8"
Roll Welding With Backing-Up Ring			
6"	3/16" or 7/32"	1/4"	
8"	7/32" or 1/4"	1/4"	
10"	1/4" or 5/16"	5/16" or 3/8"	
12"	1/4" or 5/16"	5/16" or 3/8"	
14"	5/16"	5/16" or 3/8"	
16"	5/16"	3/8"	
18"	5/16"	3/8"	
20"	5/16"	3/8"	
22"	5/16"	3/8"	
24"	5/16"	3/8"	
26"	5/16"	3/8"	
Position Welds Without Backing-Up Ring "Stove Pipe" or "Tie-in" Method			
6"	5/32"	3/16"	3/16"
8"	5/32"	3/16"	3/16"
10"	5/32" or 3/16"	3/16"	3/16"
12"	5/32" or 3/16"	3/16"	3/16"
Position Welds With Backing-Up Ring			
Use 3/16" rod for all beads on all sizes of pipe.			

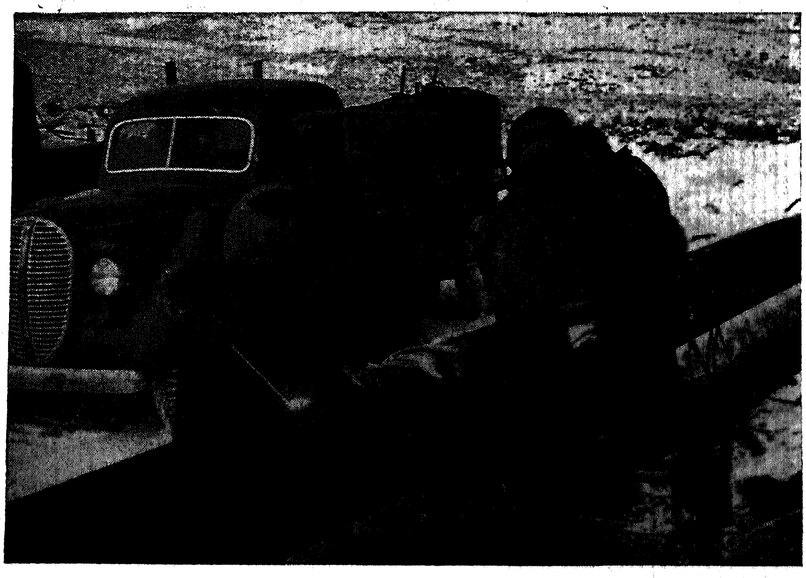


Fig. 1340. Building an 18-in. gas line in Wyoming in subzero weather. Engine driven welders with anti-freeze in the radiators can be used in extremely cold weather where other welding processes requiring quantities of water would not be practical.

Table II—Average Speeds of Pipe Line Welding

(The following data is not the actual time consumed in making each individual weld, but is the average time consumed in making all welds on an average length pipe line from start to finish of the job, and includes delays, breakdowns and moving time. In other words, it is the average production that can be expected per welder per hour on pipe line construction.)

Size Pipe	Average Welds Per Hour
Roll Welding Without Backing-Up Ring (Three Beads)	
6″	6.0
8″	5.5
10″	4.0
12″	3.0
16″	2.5
20″	2.25
22″	2.1
24″	2.0
Roll Welding With Backing-Up Ring (Two Beads)	
6″	7.0
8″	6.5
10″	5.0
12″	4.5
14″	4.0
16″	3.5
18″	3.25
20″	3.2
22″	3.1
24″	3.0
26″	2.5
Position Welding (Stove Pipe Method) Without Backing-Up Ring After 1st Bead Run by Tackers	
6″	5.0
8″	4.0
10″	3.0
12″	2.0

Table III—Amount of Rod Used to Weld Various Size Pipe

Less Without Ring Due to Close Spacing

Thickness of Pipe—¼″ to 5⁄16″

	Pounds Rod Per Weld	
Size Pipe	With Ring	Without Ring
6″	1.00	.75
8″	1.50	1.00
10″	2.00	1.25
12″	2.25	1.50
14″	2.50	1.75
16″	2.75	2.00
18″	3.00	2.25
20″	3.25	2.50
22″	3.50	2.75
24″	3.75	3.00

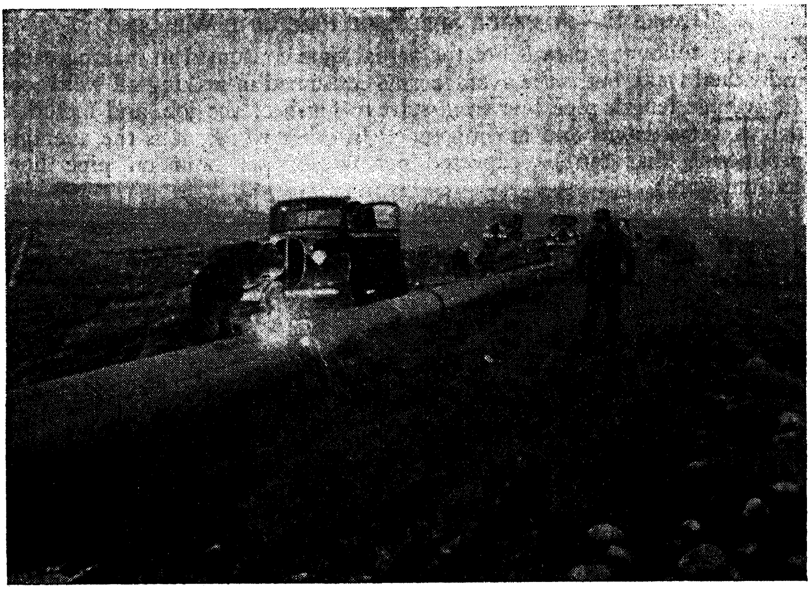


Fig. 1341. Arc welding on 18-in. gas line in Utah — total 53 miles, 6729 butt joints with back-up ring. Welded by firing line and bell-hole method an average of 103 joints per day.

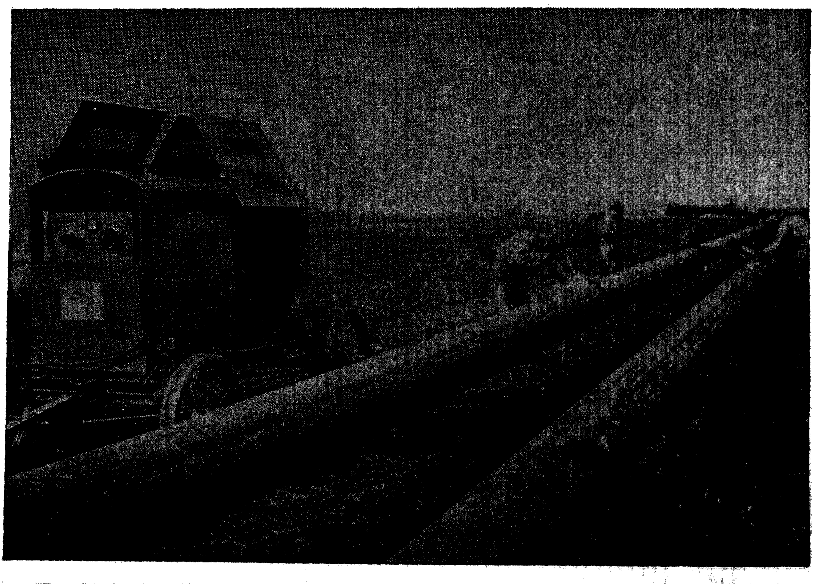


Fig. 1342. Shield-arc welding a 16-in. gas line (235 miles long) in Nebraska. Roll welds are here being made.

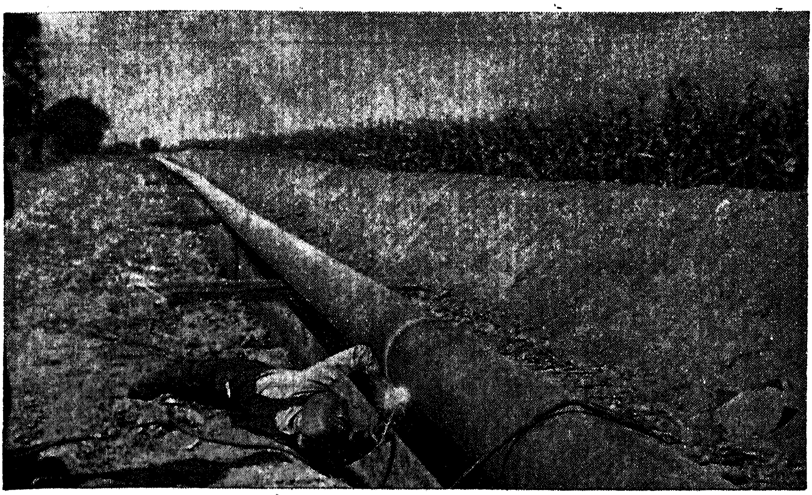


Fig. 1343. Making a bell-hole weld in 16-in. gas line as shown in Fig. 1342. Note that the line sections are supported on timbers over the ditch.

Fig. 1344. Left: Roll welding sections of 24-in. pipe for a gas line in Kansas. Right: Tack welding a liner in the end of the pipe.

TABLE IV—SPACING OF PIPE JOINT FOR WELDING

Size Pipe	Average Spacing
4″	$\frac{1}{16}$″ to $\frac{1}{8}$″
6″	$\frac{1}{16}$″ to $\frac{1}{8}$″
8″	$\frac{1}{16}$″ to $\frac{1}{8}$″
10″	$\frac{1}{16}$″ to $\frac{1}{8}$″
12″	$\frac{1}{16}$″ to $\frac{1}{8}$″
Roll and Position Welding with Backing-Up Ring	
For all sizes of pipe, use a space of from $\frac{3}{16}$″ to $\frac{7}{32}$″	
POSITION WELDING WITHOUT BACKING-UP RING	
6″	$\frac{1}{16}$″
8″	$\frac{1}{16}$″
10″	$\frac{1}{16}$″
12″	$\frac{1}{16}$″

TABLE V—AMPERAGE AND VOLTAGE FOR VARIOUS SIZES OF ROD

Size Rod	Amperage	Voltage
	Roll Welding	
$\frac{1}{8}$″	100-150	30-40
$\frac{5}{32}$″	125-200	30-40
$\frac{3}{16}$″	150-225	30-40
$\frac{7}{32}$″	175-300	30-40
$\frac{1}{4}$″	200-325	30-40
$\frac{5}{16}$″	250-400	30-40
$\frac{3}{8}$″	350-500	30-40
	Position Welding	
$\frac{1}{8}$″	100-150	25-40
$\frac{5}{32}$″	125-200	25-40
$\frac{3}{16}$″	125-200	25-40

Fig. 1345. Erecting a river crossing of 12-inch pipe for a gathering system between an oil field and a cracking plant where casing head gas will be converted into gasoline. A parallel 4-in. arc welded line will carry residue back to the well. Joints are V-grooved.

Fig. 1346. Building a crossing of 10-in. oil lines on the Mississippi River. Extra heavy pipe (.50-in. wall thickness) is used. Joints are plain butt with 30° bevel. All welding is done on the barge. River clamps (visible in the picture) are bolted over each joint and the line is lowered into the river. When tested under air pressure these five river crossing lines were found to be 100% OK.

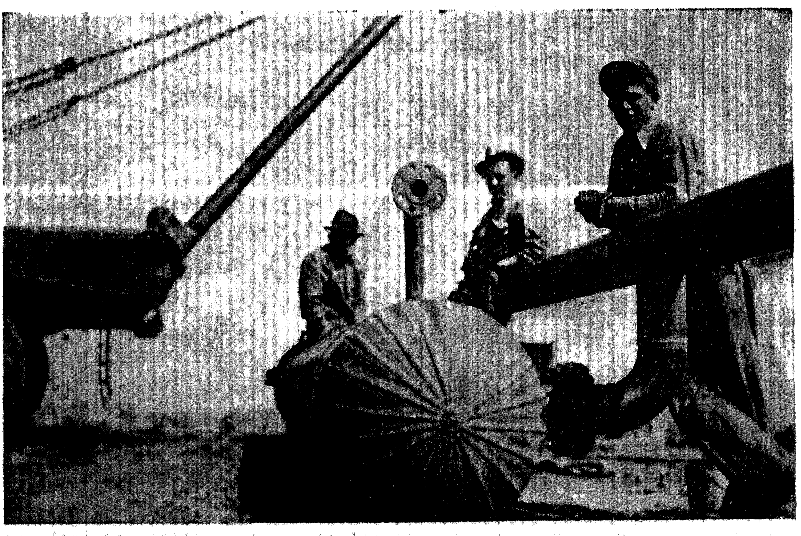


Fig. 1347. Bull plug for a header fabricated from 24-in. pipe by flame cutting joints in the ends and welding them into an "orange peel" section as shown.

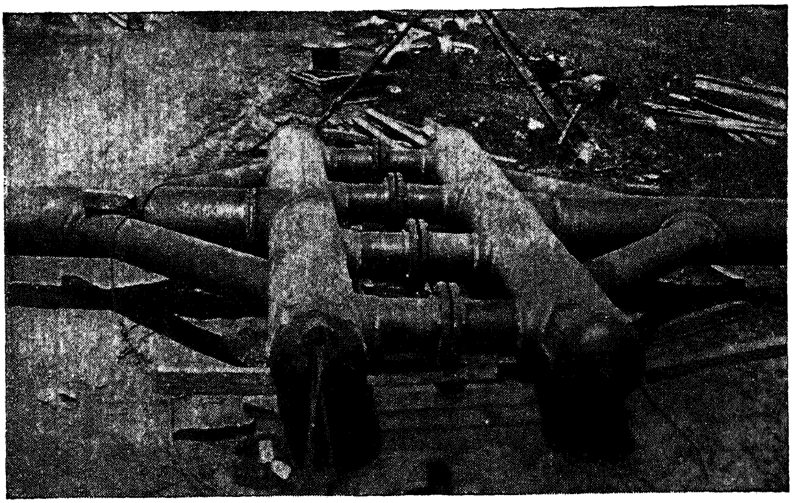


Fig. 1348. Headers for a 22-in. gas line river crossing, fabricated from pipe. Assembly in pairs as shown permits accurate alignment.

Fig. 1349. How a 22-in. gas line crossed a river. The line branches out into four 12-in. lines as shown. The 12-in. lines are roll welded into sections and joints are reinforced by welded on sleeves. Headers are fabricated from stock pipe and fixtures on the river crossing site. The roll welded sections are bell-hole welded, then the ditch is filled in.

Pipe Line Repair

The life of pipe buried in the earth depends upon several factors. First, how well the pipe is protected from contact with the medium surrounding it by means of paint and wrapping. Second, upon the corrosive properties of the medium surrounding the pipe. Under ordinary soil conditions, steel pipe that is properly protected usually lasts twenty to thirty years before replacement or reconditioning is necessary. However, because the corrosive properties of soils vary so widely, even along the same pipe line, many maintenance departments find it advisable to carry on a systematic program of leakage tests, inspection and repair at all times, regardless of the length of service of the lines.

Various methods are used today to reclaim corroded pipe and in most cases the reconditioned pipe line is made as good as new, at substantial savings over replacement cost.

Repair of Oil Lines Under Pressure.—Ordinarily, oil lines can be reconditioned by means of arc welding without interrupting the service of the line. The line is kept operating under normal pressure, avoiding shutdown losses and, moreover, precluding the possibility of gas pockets which might be encountered in an empty or partly filled line.

First, the line is dug up, a section at a time (see Fig. 1350). Sections ranging in length from a few hundred feet to a mile or two are uncovered at one time, depending upon the length of the line to be reconditioned, the terrain, etc. On long lines where a mile or two of pipe can be raised at one time, several crews of welders can work on that section.

All dirt, rust and scale are then removed from the pipe. One type of cleaner is a device which wraps around the pipe and by hand operation is rotated and moved along the pipe, scraping off all foreign material. (See Fig. 1350). Where long sections of line are uncovered and are worked on by several crews, a gas engine driven cleaning machine which rides on the pipe is generally employed. To insure the pipe being perfectly clean it is often washed with gasoline after the scale and rust have been removed.

Careful inspection, aided by a pointed hammer, reveals the pits and corroded areas. The inspectors employ special gauges used for determining the depth of the corroded areas. If the pit is deeper than 10% to 15% of the wall thickness, it is repaired. Pit holes are chalked by the inspector.

If the chalked pit holes are not too numerous they are filled in with weld metal by the welder. Care should be taken in welding pit holes so as not to burn through the pipe or maintain the arc for an undue length of time at any one spot. However, since the welding arc works fast and the heat is soon dissipated, there is little possibility of danger with this welding process. Pit holes filled in this manner vary in size up to areas of almost a square foot. Often more than one layer of weld metal is required to bring up the corroded spots flush with the pipe. 1/4-inch mild steel shielded arc electrode (or 3/16-inch size for overhead welds) is generally used.

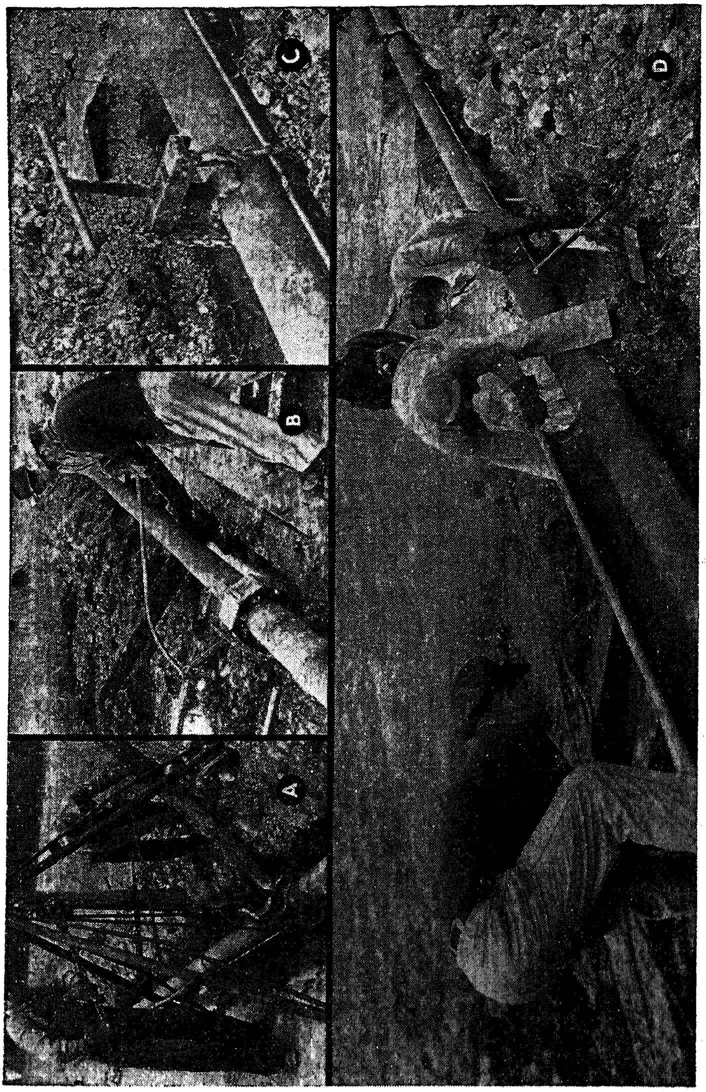


Fig. 1350. Reconditioning a 10-inch oil line in southeast Texas. About 20 years old. Many corroded spots leaked. Steps required: 1. Digging out oil line. 2. Lifting line (See A). Supported on timber. 3. Cleaning corroded section (see B). 4. Fitting on new steel plates with shock welded clamp (see C). 5. Tack welding plate in place. Finish welding (see D). 6. Painting and wrapping. 7. Relaying line. —— Half section of 3/8-inch rolled plates applied half way or full way around pipe, depending upon extent of corrosion. Welded with two passes 3/16-inch and 1/4-inch Type A shielded arc electrode.

Corrosion of the pipe is usually three to four times as bad on the bottom of the pipe as the top half. Because of this, most companies turn the pipe over (by unscrewing 180° in coupling) so that the old top will be the bottom of the line when it is relaid. This is done where the old screwed couplings are to be welded to the pipe and especially in cases where the condition of the pipe is bad and where there are not too many bends.

Where corrosion is more extensive it is usually advisable to weld on sections of new steel either half way or all the way around the

worn pipe. Following is the procedure used by one large oil company.

Half-soles are cut in any desired length from new pipe of the same diameter size as the pipe being repaired, or are rolled to proper shape from new steel plate about $\frac{3}{8}$-inch thick. These are then clamped (see Fig. 1350) and tack welded in place. The clamp is then removed and the half-sole is lap welded along both longitudinal and girth seams, providing a jacket that is permanently tight.

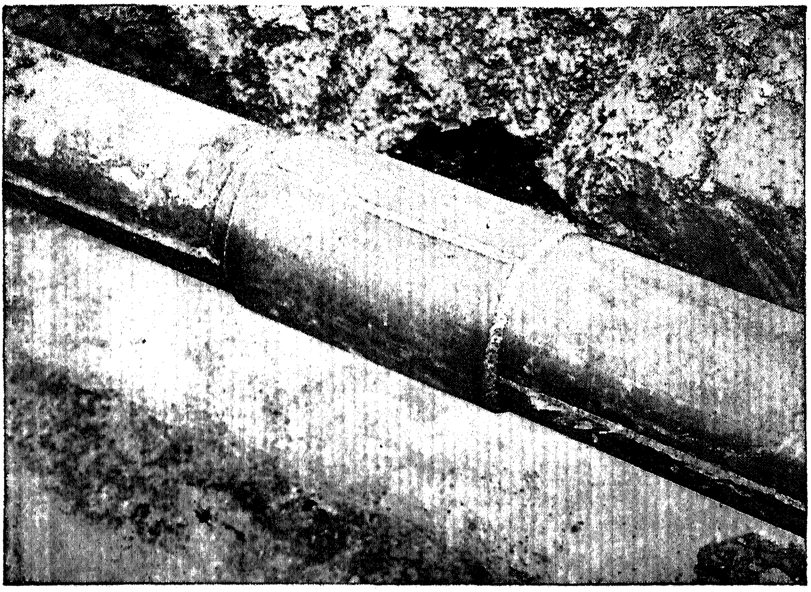


Fig. 1351. Repair at a pipe joint in 10-inch oil line. Half-sole is welded over coupling as shown. Note section on right has been half-soled all around. Section on left has the lower half half-soled.

If there are leaks in the old pipe through which oil is escaping, a cardboard gasket may be placed over the hole and the half-sole plate is then fitted over the gasket so as to shut off the oil until welding is completed.

Two beads are recommended for these welds. The first bead is run with $\frac{5}{32}$-inch mild steel shielded arc electrodes. The second bead is made with $\frac{3}{16}$-inch or $\frac{1}{4}$-inch electrodes. A combination of these two beads gives a permanently leak-proof joint. The girth welds (vertical and overhead) are usually made with $\frac{3}{16}$-inch electrode.

If pipe at collars or couplings is not in very bad condition, showing only minor leakage, both sides of the collar can be lap welded to the pipe. These girth welds are usually made with $\frac{3}{16}$-inch electrode.

When leakage conditions at collars are bad, the collar is usually jacketed with steel half-soles, cut from new pipe.

After the line is reconditioned by arc welding, a protective coating of paint is usually added, and in some instances the line is wrapped for further protection. It is then re-laid in the ditch and covered.

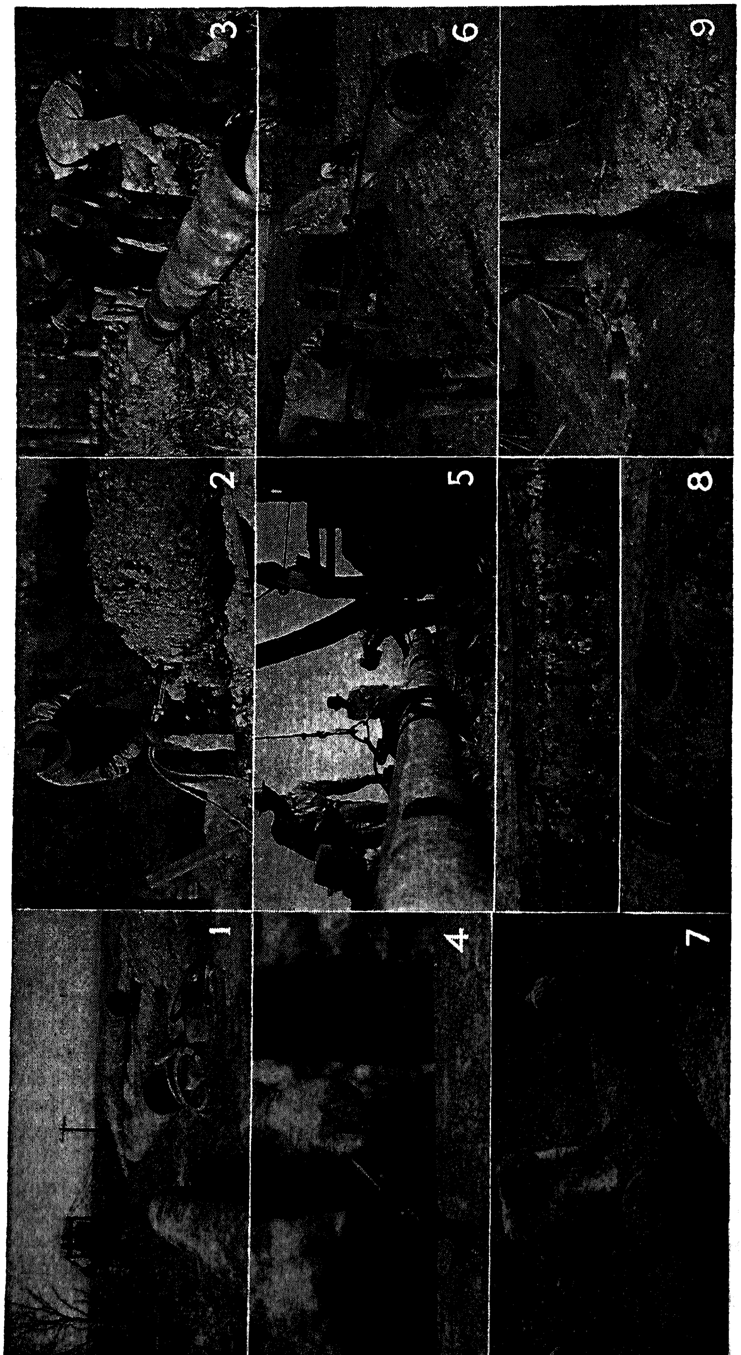


Fig. 1352. Reconditioning 25 miles of 16-inch main gas line in central Ohio. The main steps illustrated are discussed in the text.

Repair of Gas Lines Under Pressure.—Many of these natural gas pipe lines are repaired in operation with full pressure on, with a procedure like that used in the case of oil lines as discussed above. Welding under pressure is considered more safe than welding a line that is full of gas without pressure because under this latter condition, explosive mixtures of gas and air might be encountered.

Where small leaks are encountered, a quick bead can be run over the leak to stop it, then a permanent weld made. If the leak is bad, a patch with cardboard jacket should be clamped to the pipe and then welded around the patch. As a precaution, it is advisable to have a shovel-full of loose dirt and a gas fire extinguisher handy when welding under leaky conditions.

Repairing Gas Lines Out of Service.—Many companies find it necessary in repairing gas lines to recondition their couplings as well as the pipe. In a case such as this, where the line is given a complete overhaul, service on the line is naturally discontinued. There are two general practices used in reconditioning lines in this manner.

Some companies do their reconditioning work at a central plant; others do this work along the pipe line right-of-way. The procedure used in each case is practically the same. Where the central plant method is used, the worn sections of pipe are usually replaced with new or reclaimed pipe as soon as they are removed, thus requiring a stock of replacement pipe. See Fig. 1353.

The procedure used by a large gas company in a complete overall reconditioning job with all work done along the right-of-way is illustrated in Fig. 1352. The particular case is that of a 16-inch line, 25 miles long, originally laid in 20-foot lengths, joined by couplings, about twenty-five years ago. The steps illustrated are:

1. After ditch was dug, pipe was lifted out and supported on timbers over ditch.
2. Coupling bolts were torch-cut and pipe was rolled away from ditch.
3. Pipe cleaning crew with hammers and chisels removed earth and rust scale. Corroded spots were well cleaned to expose sound metal.
4. An inspector chalk-marked all corroded areas which were to be built up with weld metal.
5. Four 20-ft. pipe lengths were joined into one 80-ft. section. Joints were plain end butt type with back-up ring. The pipe was lined up and tacked as shown.
6. Mounted on dollies, the pipe was roll-welded with two passes of $\frac{5}{16}$-inch Type A mild steel shielded arc electrode, averaging 3 joints per hour per man. Each section was stress-tested and drop-pressure tested.
7. Corroded pits were filled in with $\frac{5}{16}$-inch Type A mild steel shielded arc electrode.
8. Filled-in areas varied in size from small spots to large patches a foot square.
9. Majority of line was relaid without protective coating. It is claimed that the reconditioned line is in better shape than the original when new.

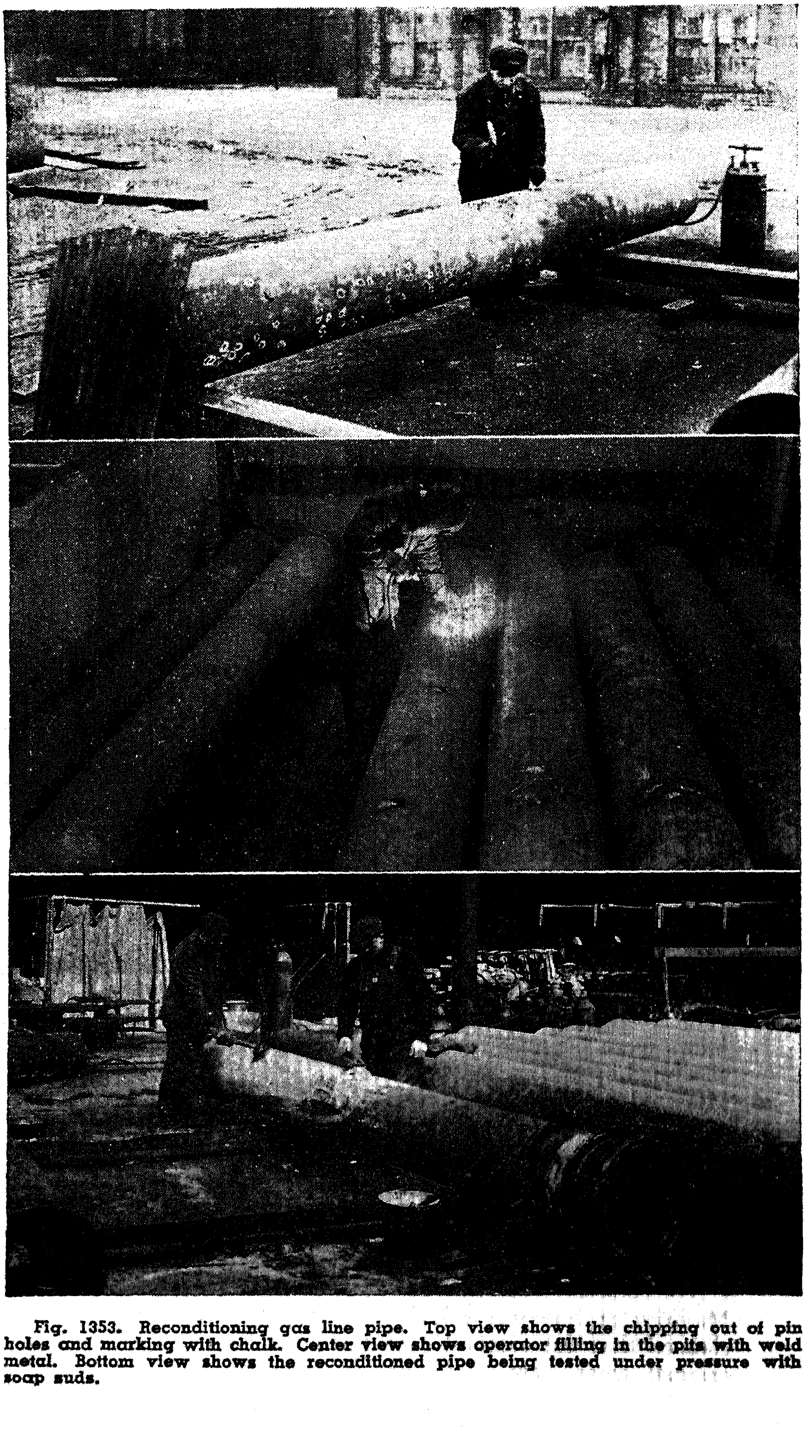


Fig. 1353. Reconditioning gas line pipe. Top view shows the chipping out of pin holes and marking with chalk. Center view shows operator filling in the pits with weld metal. Bottom view shows the reconditioned pipe being tested under pressure with soap suds.

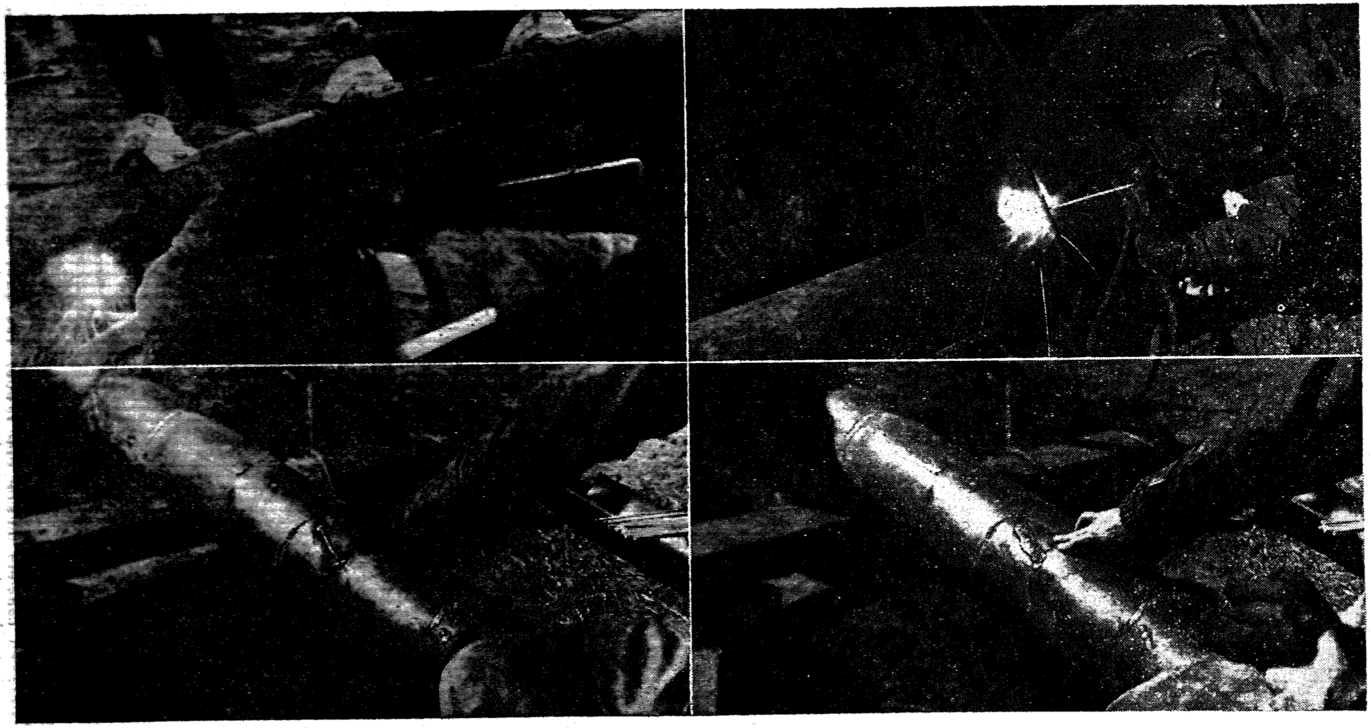


Fig. 1354. Reclaiming 8-inch gasoline line, operated under 50% normal pressure. About 10 years old. Procedure for welding on half sole same as that for oil lines discussed previously (see above left and right). Where pits are scattered they are filled up with shielded arc weld metal. To avoid burn-through in low spots, one or more bare welding rods are tacked across the pit as shown in the illustration below, left. This is then welded over as shown on the right.

Repair of Other Kinds of Pipe Lines.—While the above procedures are those used generally for oil and gas lines, arc welding can be applied for substantial savings to the reclamation of pipe lines carrying other substances. The procedure would then be varied in accordance with the nature of the substance and the type of pipe line used.

On a 10-inch gasoline line reconditioned in the Mid-Continent field (Fig. 1354), the pipe was all welded with the line operating under full 600 pounds pressure. Areas which were badly corroded were half-soled as outlined for the oil line in previous paragraphs. Where corrosion was spotty, the pits were filled with weld metal. In order to minimize heating of the gasoline where pits were deep, they were covered with one or more lengths of bare rod, tack-welded across the pit and then welded over as shown in Fig. 1354.

Pipe Lines (Water)

As in the case of oil and gas lines, arc welding assures permanently tight, leak-proof joints which are stronger than the pipe itself. A large number of water lines and penstocks in sizes up to 20 feet diameter have been field welded by the shielded arc process. The type of welded

Fig. 1355. Welding on the outside seam of a bell and spigot joint in a 51-inch feeder line of the Colorado River aqueduct system. This line has a heavy protective layer of reinforced concrete outside and inside. The girth joints are also welded on the inside. Fabrication of this pipe is illustrated in Figs. 1321 and 1322.

joint used in water lines depends upon the size and thickness of pipe and the operating pressure of the line. In the smaller size lines (up to 36-in. to 56-in.) the bell and spigot type joint, welded from the outside only is used. Larger size lines such as the 51-inch line shown in Fig. 1355 have bell and spigot type joints which are welded both inside and outside. Often, too, lines such as shown in Fig. 1356 of large diameters have plain butt joints with reinforced band which is welded on both ends. Here too the joints are beveled and welded on the inside.

Because of the large diameters used in water lines, roll-welding is impractical. The circumferential joints are made as in the case of bell hole welding, joining sections which are relatively short. For example, in the construction of the 51-inch line shown in Fig. 1355, bell and spigot type joints are used, welding inside and outside, joining 30-foot sections. In this case, the pipe is protected against corrosion inside and outside by a coating of reinforced cement which brings the total weight of each 30-foot section to approximately seven tons (three tons of which is steel pipe).

The following table gives data pertaining to the welding of girth seams for large diameter pipe used in the construction of siphons.

Length of Siphon	Diameter	Plate Thickness	Type of Weld	Inside of Girth Joints			Outside of Girth Joint		
				How Welded	Current	Lbs. Rod* Per Joint	How Welded	Current	**Welding Speed
8000′	84″	1/4″	Square Butt	Manually	38V250A	5¾ Lbs.	Automatically	34V350A	1.32 Ft./Min
	84″	5/16″	" "	"	" "	" "	"	35V400A	" " " "
	84″	3/8″	" "	"	" "	" "	"	38V600A	" " " "
2800′	81″	5/16″	" "	"	" "	5 Lbs.	"	35V400A	" " " "
1800′	52″	1/4″	" "	"	" "	3.3 Lbs.	"	34V350A	" " " "
	52″	5/16″	" "	"	" "	" "	"	35V400A	" " " "
	52″	3/8″	" "	"	" "	" "	"	38V600A	" " " "
1000′	111″	1/4″	" "	"	" "	7.0 Lbs.	"	34V350A	" " " "
	111″	5/16″	" "	"	" "	" "	"	35V400A	" " " "
	111″	3/8″	" "	"	" "	" "	"	38V600A	" " " "
300′	96″	1/4″	" "	"	" "	6.0 Lbs.	"	34V350A	" " " "
	96″	5/16″	" "	"	" "	" "	"	35V400A	" " " "
	96″	3/8″	" "	"	" "	" "	"	38V600A	" " " "

*Includes Tack Welding.
**The pipe was set to rotate at about the same speed, that is, 1.32 feet per minute for welding all thicknesses with the automatic welder, the depth of penetration of the weld being controlled by the current. The current setting was about as shown in the table.

Various water line installations are shown on the following pages.

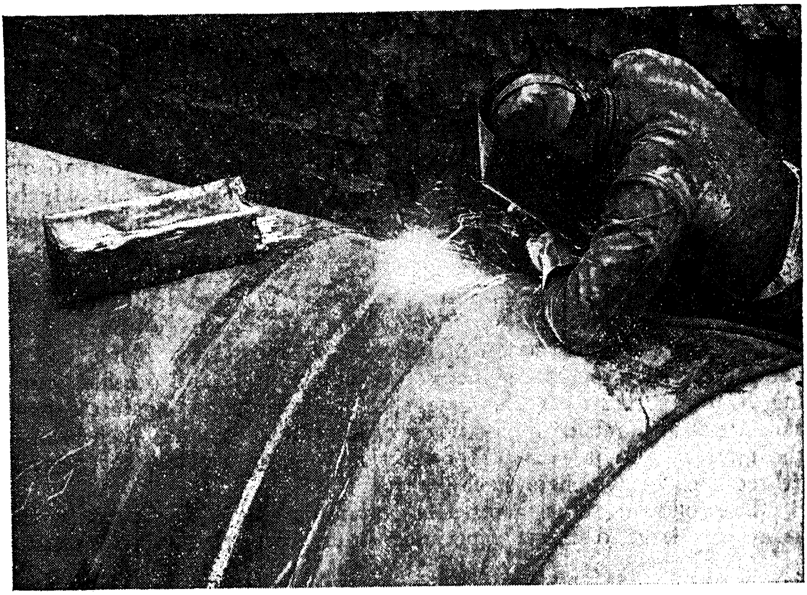


Fig. 1356. A 108-in. water supply line with butt welds reinforced by a steel band as shown. Girth seam is welded inside and outside.

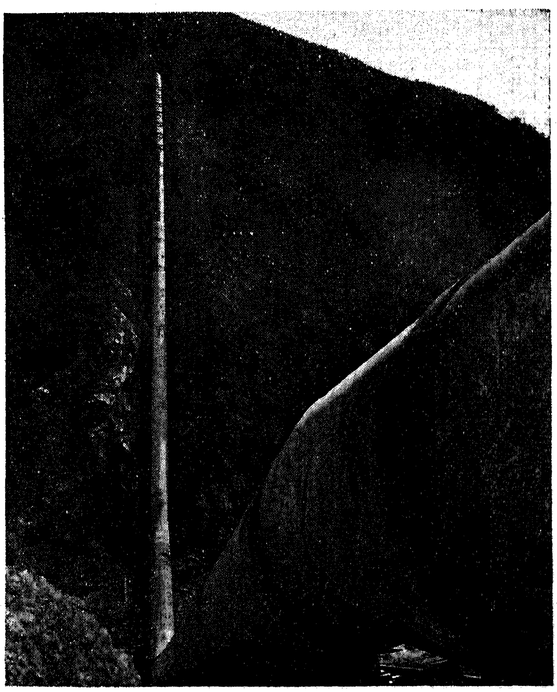


Fig. 1357. Arc welded water line of 90-in. diameter. Joint is plain butt welded inside and outside and reinforced by a band over the outside of the joint as shown.

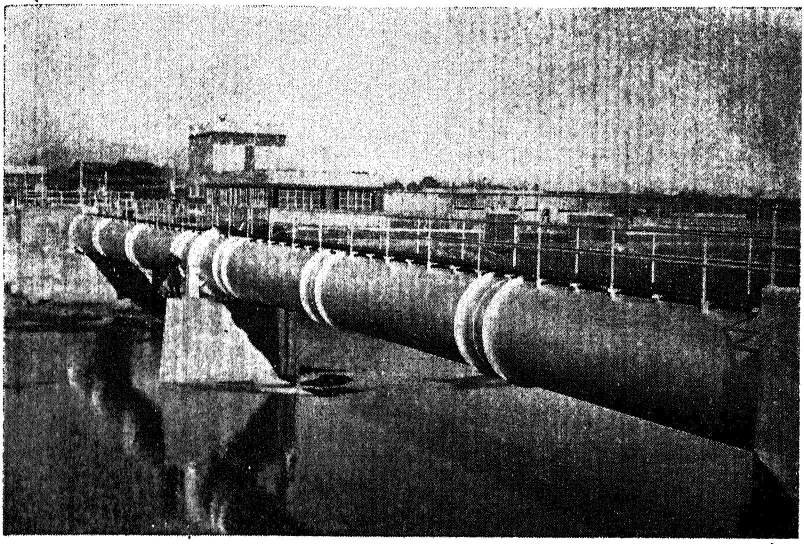


Fig. 1358. Arc welded design with stiffener rings prevents distortion at points of support and permits self-supporting spans of 105 feet in the construction of this 78-inch sewage line river crossing.

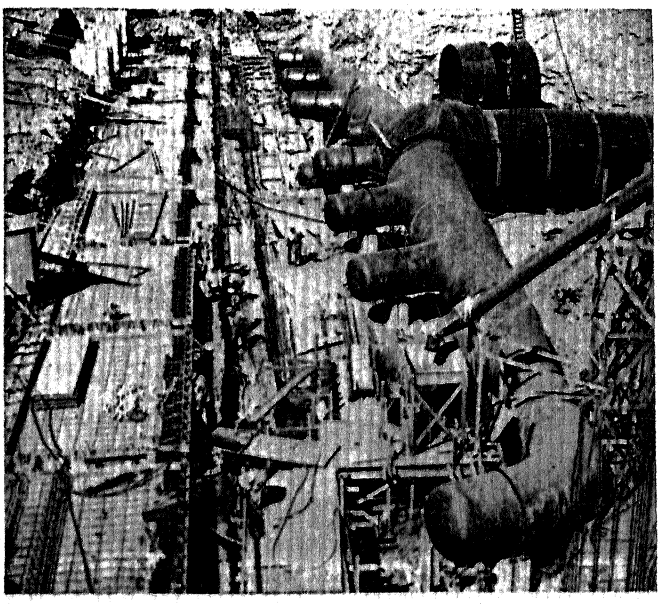


Fig. 1359. Inlet manifold to one of the pumping stations of a large aqueduct. It is fabricated entirely by arc welding.

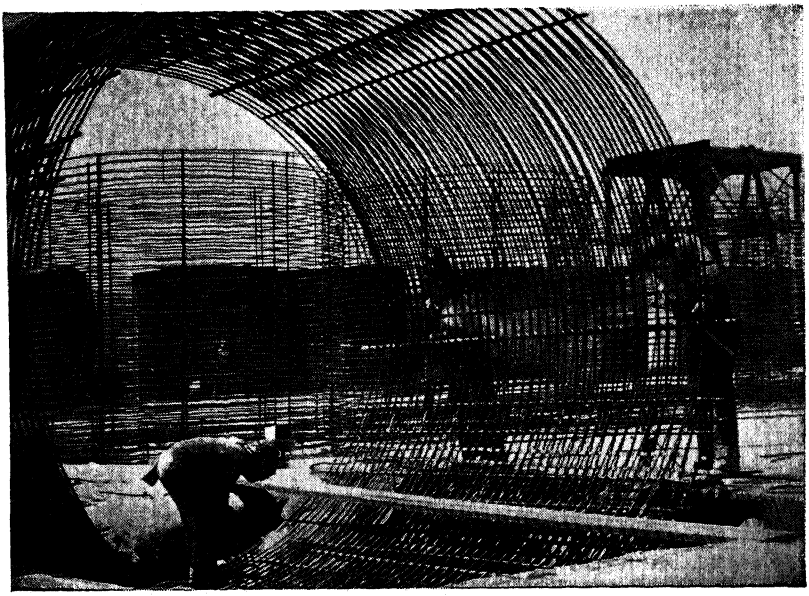


Fig. 1360. Fabricating steel reinforcement for concrete pipe sections for a large aqueduct. Each section of pipe weighs 44 tons.

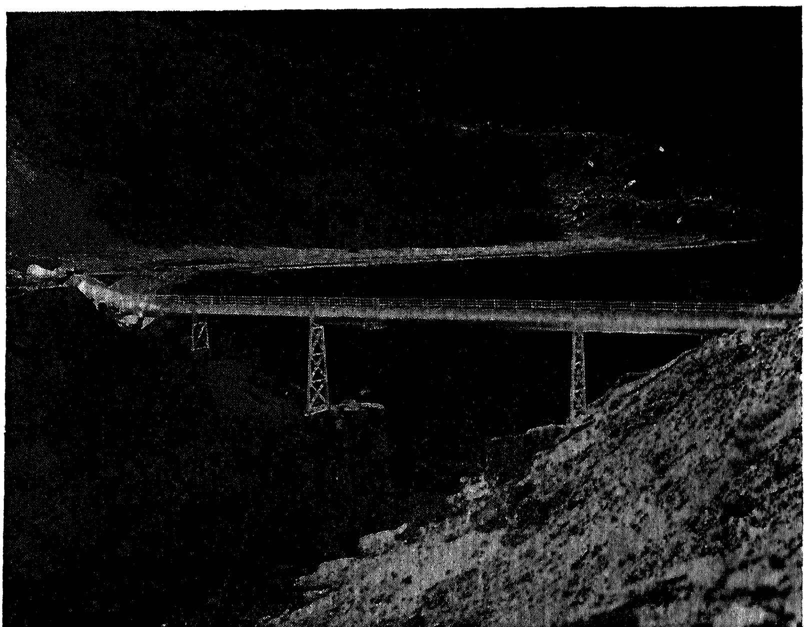


Fig. 1361. Shoshone River siphon near Cody, Wyoming crosses this 360-ft. wide canyon with a record-breaking 150-ft. self-supporting span in center. Pipe is 10 ft. 3 in. diameter. The plate thickness varies from $\frac{7}{16}''$ to $1\frac{5}{8}''$, the latter thickness being used only at the two points of support. The span has a camber of $1\frac{1}{2}''$ in order to obtain a level pipe when the siphon is full of water.

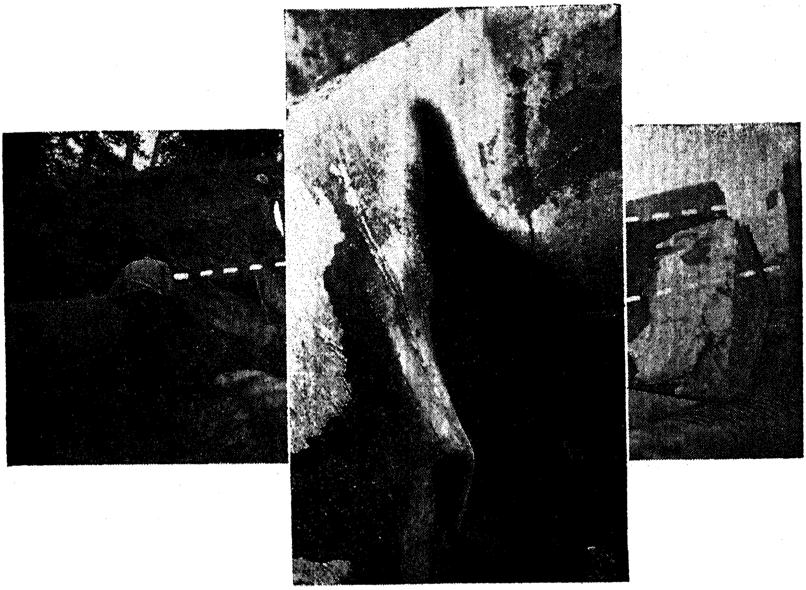


Fig. 1362. An ice jam in the Rockies caused the wash-away of earth under this 85-inch water line, causing the pipe to drop as shown. Inset photo shows close-up at plain butt welded joint. It crumpled but it did not crack.

Fig. 1363. River crossing of all-American canal comprising two pipes each 15½ ft. i.d.—ten sections each 71 ft. 7 in. long. Pipe is fabricated from ½-inch and ⅝-in. plate. Longitudinal seams were welded automatically. Girth seams and other structural welding were made with Type A and Type C (deep groove) mild steel shielded arc electrodes.

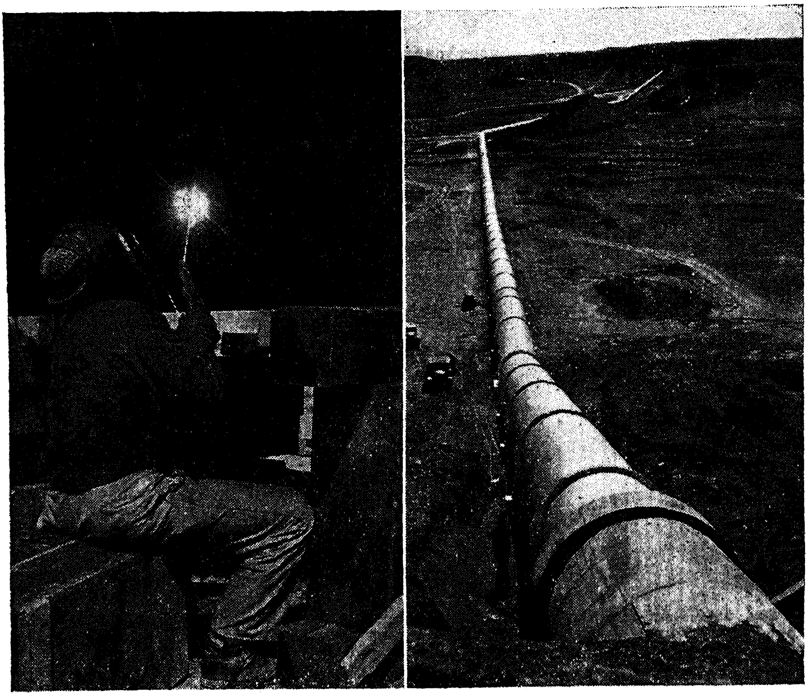


Fig. 1364. Buck Springs Creek siphon in Wyoming. Total length is 3488 ft. with 3208 ft. of welded steel pipe and 280 ft. of concrete pipe and transitions. Diameter is 8 ft. 8 in. Plate thickness is 3/16" and 3/8". Pipe was shop fabricated in sections 20 ft. long. The siphon has stiffeners and rocker supports at 40 ft. centers.

Piping

Hundreds of miles of piping systems welded in shop and field have been installed in office buildings, hospitals, schools, industrial plants, power houses and ships. Central heating plants also distribute their steam many miles through mains installed by the electric arc process.

The advantages of arc welded piping systems include permanently tight connections of greater strength and rigidity, less resistance to flow due to elimination of projections inside the pipe, more pleasing appearance, easier and cheaper applications of insulation, simplification of design due to flexibility of design of fittings, and elimination of many fittings required by mechanically connected systems.

The illustrations shown on the following pages bring out these advantages.

The following procedure information on the arc welding of piping is based on the experiences of many fabricators and contractors.

The chart in Fig. 1365 provides easy reference for obtaining the amount of electrode and time required to butt weld pipe in a horizontal position.

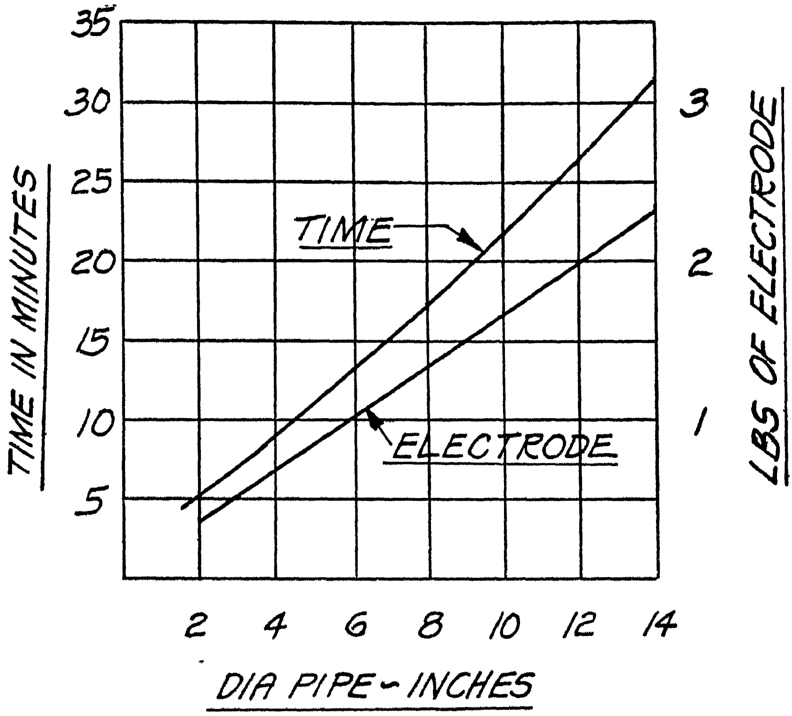


Fig. 1365.

The following table and Figs. 1366 to 1368 contain procedure data, speeds and amount of electrode required for welding butt joints in standard weight pipe in horizontal position.

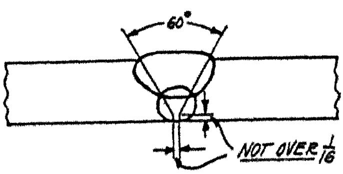


Fig. 1366.

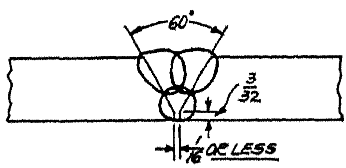


Fig. 1367.

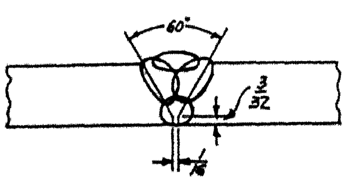


Fig. 1368.

Size of Pipe		Beads or Passes	Elec-trode Size	Current Amps.	Min. Arc Volts	Arc Time Min. Per Joint	Lbs. of Elec-trode per Joint
Dia.	Thickness						
Fig. 1366 2"	.154"	1 2	5/32"	120 140	25	5.5	.35
Fig. 1366 3"	.216"	1 2	5/32"	120 140	25	7.0	.44
Fig. 1367 4"	.237"	1 2 3	5/32" 3/16" 3/16"	120 160	25	9.0	.64
Fig. 1367 5"	.258"	1 2 3	5/32" 3/16" 3/16"	120 160	25	11.3	.81
Fig. 1367 6"	.280"	1 2 3	5/32" 3/16" 3/16"	120 160	25	13.5	.96
Fig. 1367 8"	.322"	1 2 3	3/16"	150 170	25	17.8	1.33
Fig. 1368 10"	.365"	1 2 3 4	3/16"	150 170	25	22.0	1.65
Fig. 1368 12"	.375"	1 2 3 4	3/16"	150 170	25	26.5	2.0
Fig. 1368 14"	.375"	1 2 3 4	3/16"	150 170	25	31.3	2.3

Pipe above 12″ diameter may be obtained in a great many different thicknesses of wall. Inasmuch as pipe is being used in these larger diameters for high pressure, high temperature service, and the methods at the present time are not particularly standardized, the following tabulation will indicate the number of passes to be used for the various pipe thicknesses:

Pipe Thickness	No. Passes
1/4″	3-4
3/8″	4-5
1/2″	6-8
3/4″	11-14
1″	13-16

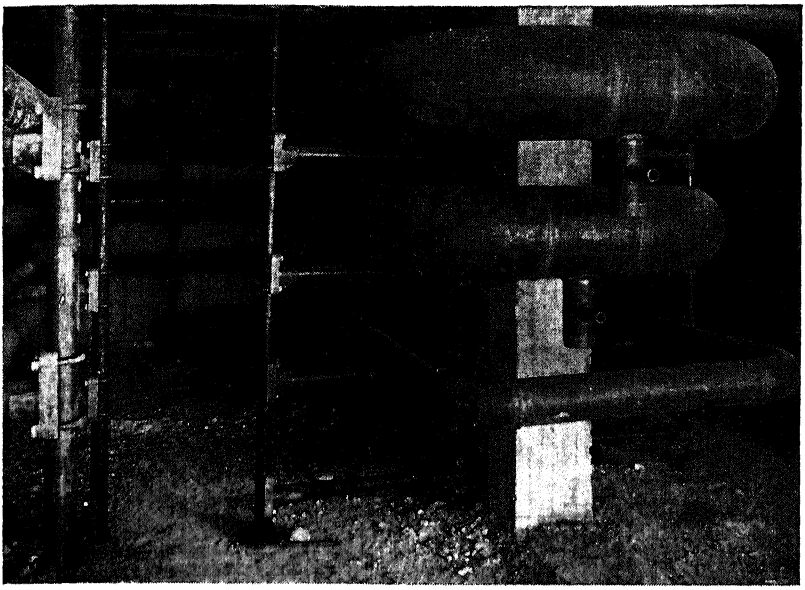


Fig. 1369. Portion of 47,000 feet of high pressure steam line installed by arc welding in a large hospital.

Fig. 1370. Funneling of a 30-inch elbow into a 42-inch straight run of arc welded piping.

The electrode size will be 5/32″ and 3/16″, depending upon the particular design, the load conditions to be met and the specifications. For example, on 14″ pipe, 3/16″ electrode is used for passes, whereas in case of very high pressure work the 5/32″ is used for the first passes and 3/16″ for the following passes.

The time taken to make the various types and sizes of pipe connections depends upon the design requirements. It may be a matter of from one-half to three-quarters of an hour on 14″ pipe, up to several hours in the case of a larger diameter pipe having greater wall thickness.

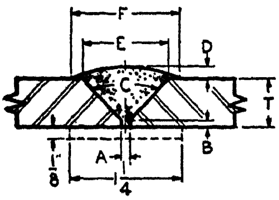


Fig. 1371
(1)

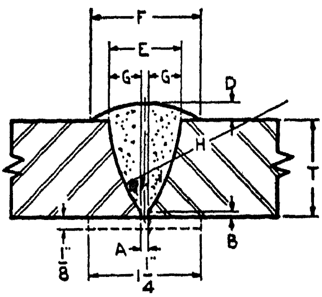


Fig. 1372
(2)

For Type "A" and "B" Welds

Thickness of Pipe (Inches)	Edge Preparation Fig. No.		A (Inches)		B (Inches)	C Total Angle	D Approx. (Ins.)	E (Inches)		F—Approx. Width of Weld (Inches)	
	Type "A" & "B" Weld	Type "C" Weld	With Back-up Ring	Without Back-up Ring				With Back-up Ring	Without Back-up Ring	With Back-up Ring	Without Back-up Ring
1/8	1	3	1/8—3/16	1/16 ± 1/32	1/16 Max.	90°	3/32	1/4 — 5/16	3/16 ± 1/32	7/16	3/8
3/16	1	3	1/8—3/16	1/16 ± 1/32	1/16 Max.	90°	3/32	3/8 — 7/16	5/16 ± 1/32	5/8	1/2
1/4	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	90°	3/32	1/2 — 9/16	7/16 ± 1/32	3/4	5/8
5/16	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	90°	1/8	5/8 — 11/16	9/16 ± 1/32	15/16	13/16
3/8	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	90°	1/8	3/4 — 13/16	11/16 ± 1/32	1 1/16	15/16
7/16	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	90°	1/8	7/8 — 15/16	13/16 ± 1/32	1 3/16	1 1/16
1/2	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	90°	1/8	1 — 1 1/16	15/16 ± 1/32	1 5/16	1 3/16
9/16	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	75°	5/32	7/8 — 15/16	13/16 ± 1/32	1 5/16	1 3/16
5/8	1	3	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	75°	5/32	15/16 — 1	7/8 ± 1/32	1 3/8	1 1/4
11/16	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	5/32	11/16 — 3/4	5/8 ± 1/32	1 1/8	1
3/4	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	3/4 — 13/16	11/16 ± 1/32	1 3/16	1 1/16
7/8	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	13/16 — 7/8	3/4 ± 1/32	1 1/4	1 1/8
1	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	7/8 — 15/16	13/16 ± 1/32	1 5/16	1 3/16
1 1/8	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	15/16 — 1	7/8 ± 1/32	1 3/8	1 1/4
1 1/4	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	1 — 1 1/16	15/16 ± 1/32	1 7/16	1 5/16
1 3/8	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	1 1/16 — 1 1/8	1 ± 1/32	1 1/2	1 3/8
1 1/2	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	1 1/8 — 1 3/16	1 1/16 ± 1/32	1 9/16	1 7/16
1 5/8	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	1 3/16 — 1 1/4	1 1/8 ± 1/32	1 5/8	1 1/2
1 3/4	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	1 1/4 — 1 5/16	1 3/16 ± 1/32	1 11/16	1 9/16
1 7/8	2	4	1/8—3/16	1/16 ± 1/32	1/16 ± 1/32	Mod.V	3/16	1 5/16 — 1 3/8	1 1/4 ± 1/32	1 3/4	1 5/8

Types of Grooves and Their Dimensions for Circumferential Roll and Position Electric-Arc Butt Welds, Including Number of Layers or Passes for Carbon Steel.

The amount of electrode metal used will depend upon the type of connection used, the scarfing or machining of the joints.

The following table and sketches give the weld and groove specifications used by a large fabricator of pipe.

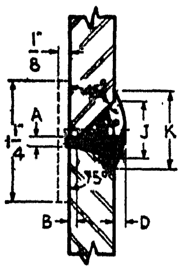


Fig. 1373

(3)

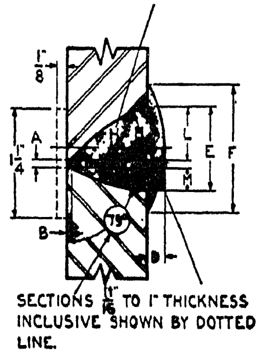


Fig. 1374

(4)

FOR TYPE "C" WELDS

G (Ins.)	H Radius (Ins.)	J (Inches) With Back-up Ring	J (Inches) Without Back-up Ring	K—Approx. Width of Weld (Inches) With Back-up Ring	K—Approx. Width of Weld (Inches) Without Back-up Ring	L (Ins.)	M (Ins.)	Approx. Number of Welding Passes Type "A" Weld	Type "B" Weld	Type "C" Weld
..	..	1/4—5/16	3/16 ± 1/32	7/16	3/8	..	..	2	2	2
..	..	9/32—11/32	7/32 ± 1/32	1/2	7/16	..	..	2	2	2
..	..	3/8—7/16	5/16 ± 1/32	5/8	1/2	..	..	3	3	3
—	..	7/16—1/2	3/8 ± 1/32	3/4	5/8	..	..	3	3	3
—	..	17/32—19/32	15/32 ± 1/32	7/8	3/4	..	..	3	4	4
—	..	19/32—21/32	17/32 ± 1/32	15/16	15/16	..	..	4	5	5
..	..	11/16—3/4	5/8 ± 1/32	1	7/8	..	..	4	5	5
..	..	3/4—13/16	11/16 ± 1/32	1 3/16	1 1/16	..	..	5	7	7
..	..	13/16—7/8	3/4 ± 1/32	1 1/4	1 1/8	..	..	5	7	7
5/16	1 3/8	..	..	..	..	7/16	..	6	9	10
5/16	1 1/2	..	..	..	..	7/16	..	6	9	10
11/32	1 3/4	..	..	..	..	1/2	..	7	11	13
3/8	2	..	..	..	..	1/2	..	8	13	16
13/32	2 1/4	..	..	..	..	9/16	1/4	9	15	18
7/16	2 1/2	..	..	..	..	9/16	5/16	10	17	20
15/32	2 3/4	..	..	..	..	9/16	3/8	11	19	22
1/2	3	..	..	..	..	5/8	3/8	12	21	24
17/32	3 1/4	..	..	..	..	5/8	7/16	13	23	26
9/16	3 1/2	..	..	..	..	11/16	7/16	15	25	28
19/32	3 3/4	..	..	..	..	11/16	1/2	17	27	30

TYPE A — Welds in which the axis of the pipe at the joint does not deviate from the horizontal by more than 30° and the pipe is rotated so that the welding may always be done in an approximately flat position.

TYPE B — Welds in which the axis of the pipe at the joint does not deviate from the horizontal by more than 30° and the pipe is not rotated so that the welding must be done in a combination of the flat, vertical, and overhead position.

TYPE C — Welds in which the angle between the axis of the pipe at the joint and a horizontal plane exceeds 30° so that the welding is done in a combination of the horizontal and overhead position.

Types of Grooves and Their Dimensions for Circumferential Roll and Position Electric-Arc Butt Welds, Including Number of Layers or Passes for Carbon Steel.

For rolling welds, see the data under "Pipe Lines (Oil and Gas)," Pages 950 to 954.

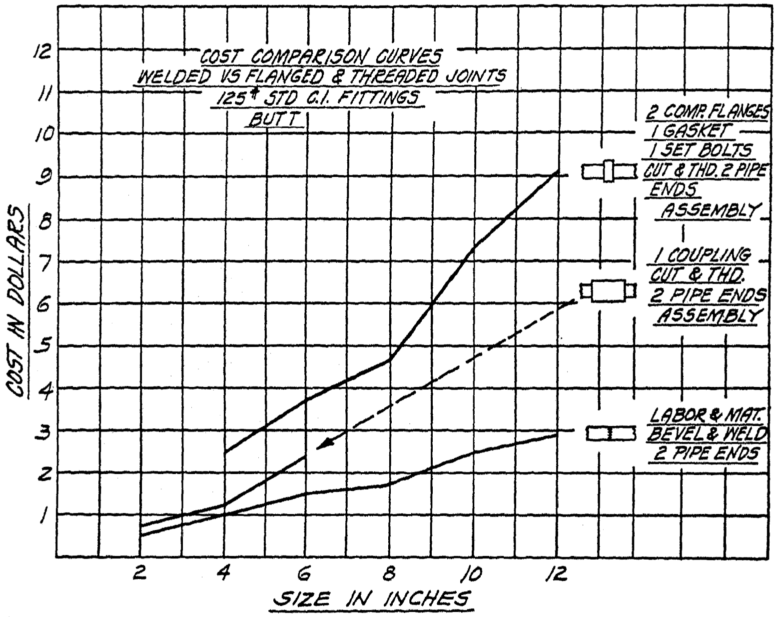


Fig. 1375. Cost comparison curves for welded, flanged and threaded joints.

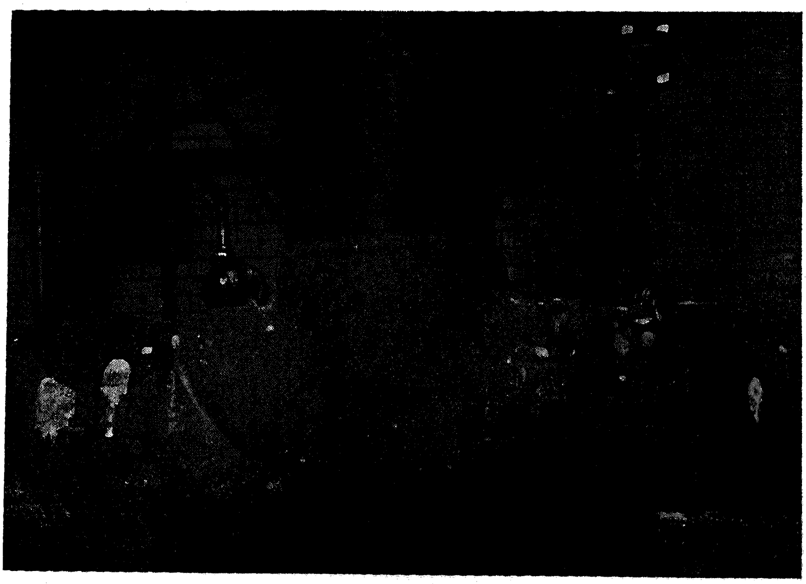


Fig. 1376. Branch connections are easily made by shielded arc welding. This connects to a power plant line operating at 650 lbs. pressure and 850° F.

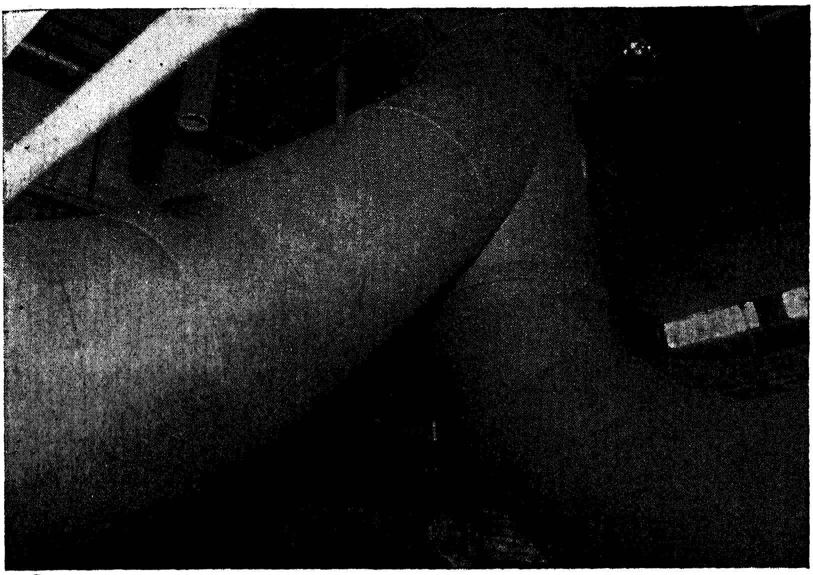


Fig. 1377. Two 42-inch curved lines for blast gases running into the inlet of a waste heat boiler.

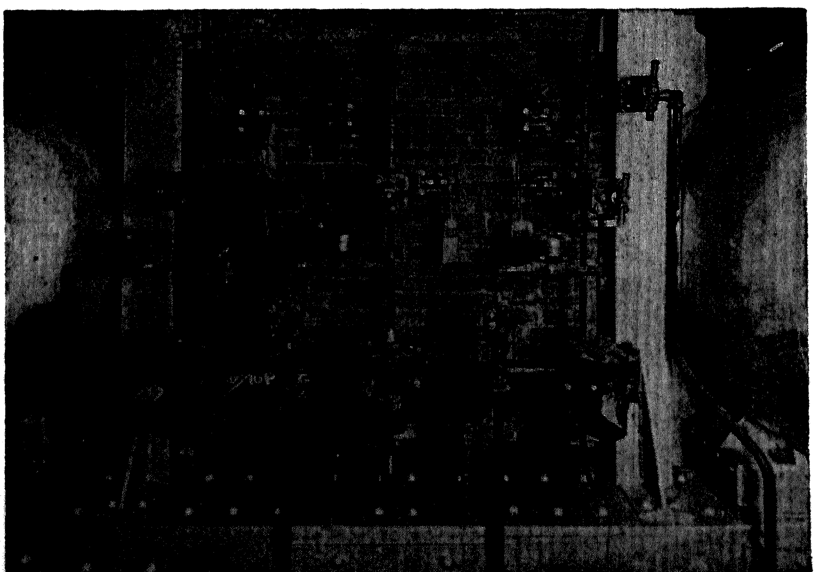


Fig. 1378. A typical application of arc welding for small piping. A power plant installation of drip piping. Note that many threaded connections are avoided.

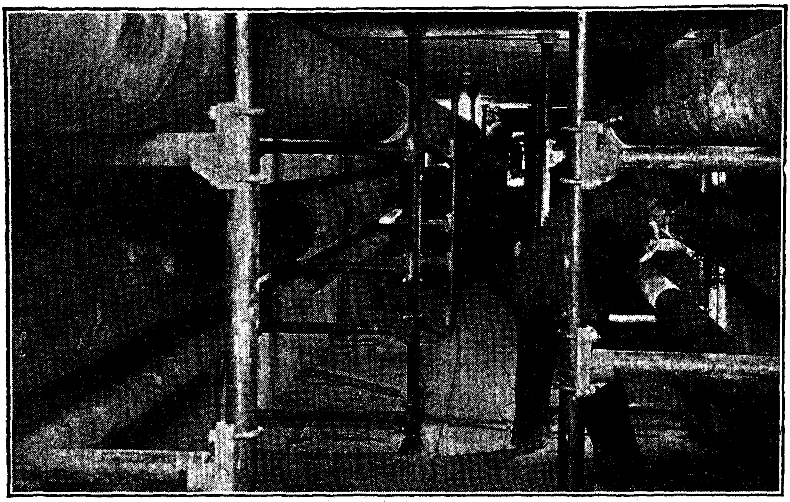


Fig. 1379. An application of arc welded steam piping involving close quarters. Here arc welding cuts installation time.

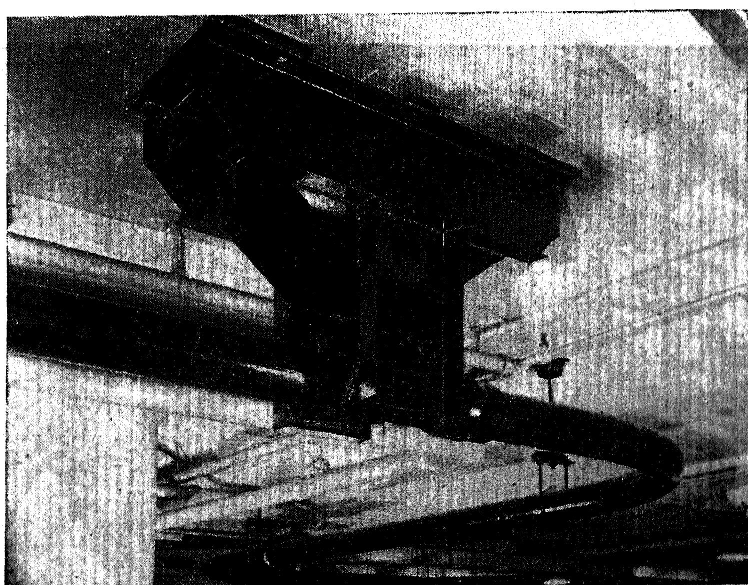


Fig. 1380. An arc welded anchorage for an arc welded 300-lb. warehouse steam line. Built from channels and shape, cut and assembled on the job. Shows the versatility of arc welding.

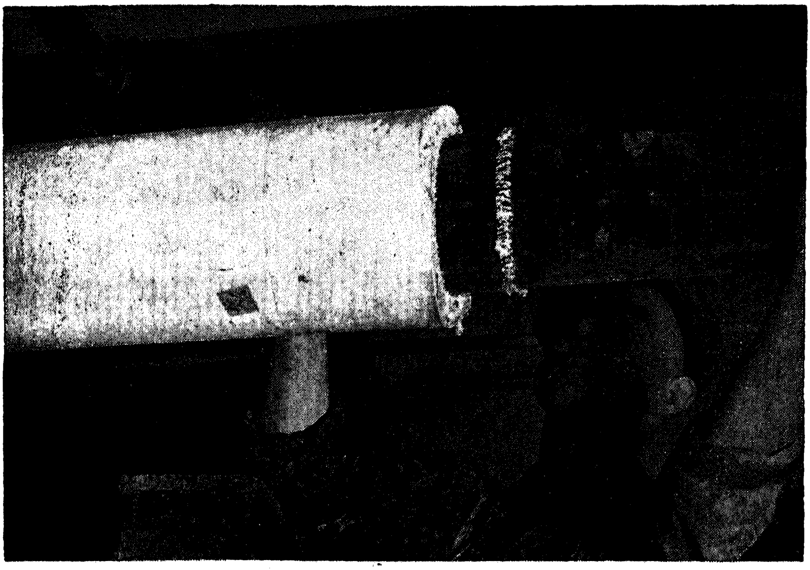


Fig. 1381. Insulating a 6-in. arc welded steam line. Absence of couplings in the line makes it possible to fit standard asbestos covering without cutting around and cementing at the joints, saving half the time formerly required.

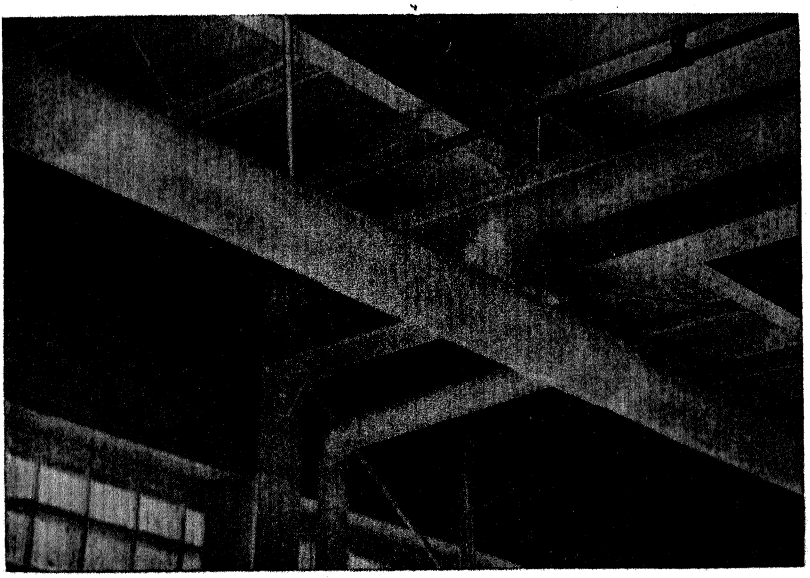


Fig. 1382. Savings in insulating time and cost are especially large where T connections are encountered. The insulation can be cut with a knife to fit the T. Cementing and patching are not required. This welded piping installation illustrates this point.

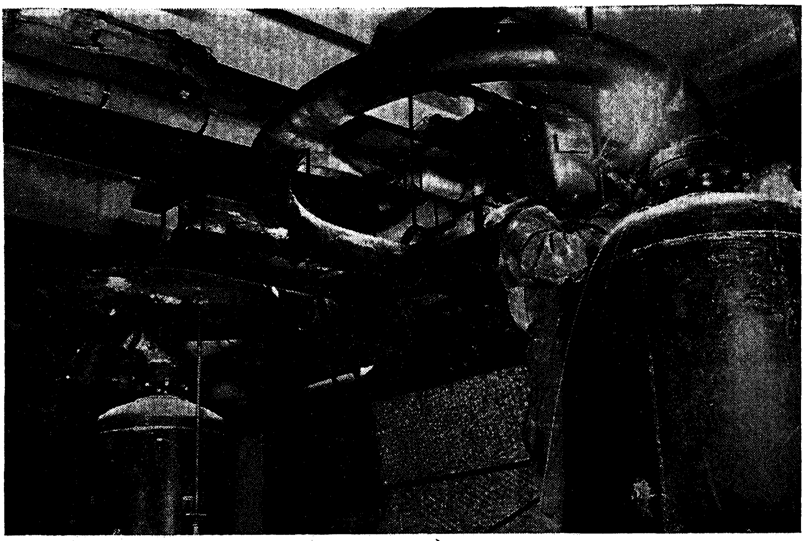


Fig. 1383. Part of arc welded piping system in an apartment house. Total length of piping 6,000 ft. varying from 2-in. to 12-in. Working pressure of steam line is 185 lbs. Contractor saved three to four times the price of his welding machine over any other method of welding or fabrication.

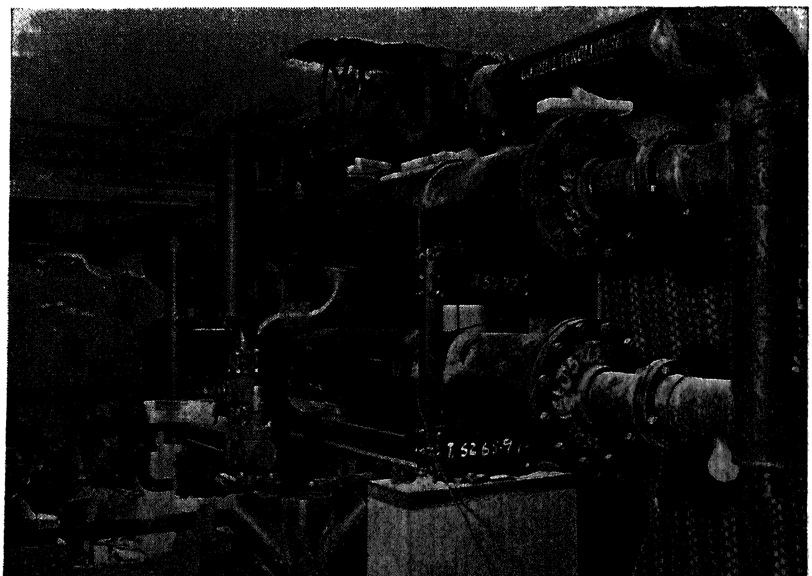


Fig. 1384. Arc welded piping installation. Part of an air conditioning system in an 8-story department store. Total of 3,400 ft. of pipe ranging from 10-in. to $1\frac{1}{4}$-in., all arc welded.

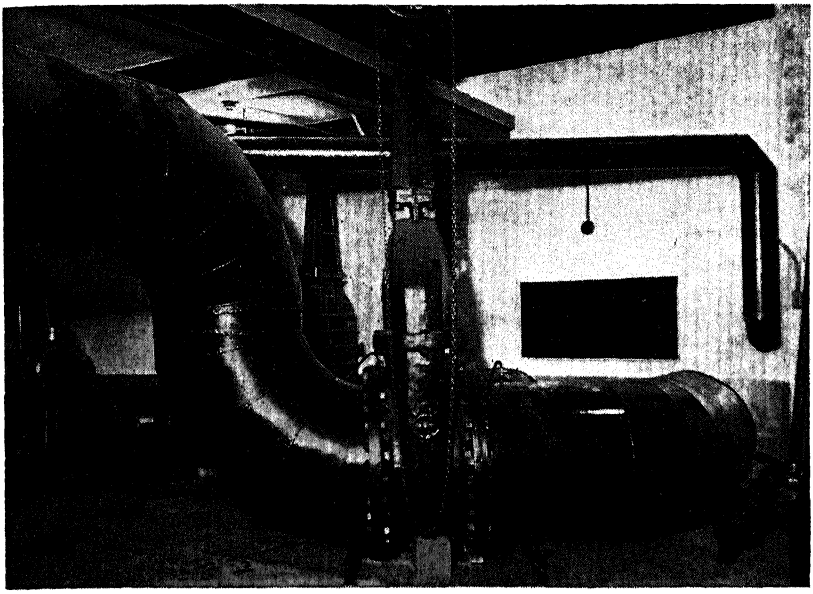


Fig. 1385. All arc welded 36-in cooling water line in a steam power plant.

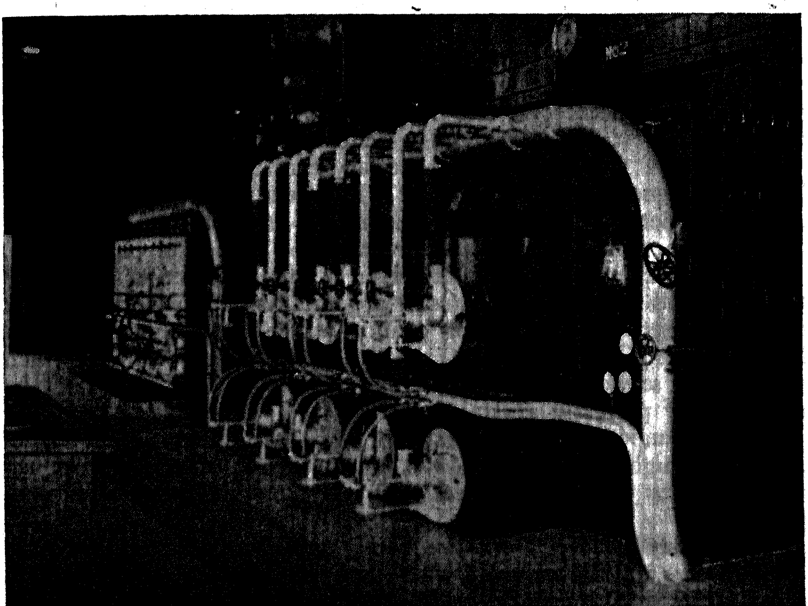


Fig. 1386. Arc welded gas feeder lines for steam boilers. 6-in. line leads in from 12-in. header in basement and branches into eight 2½-in. burner lines.

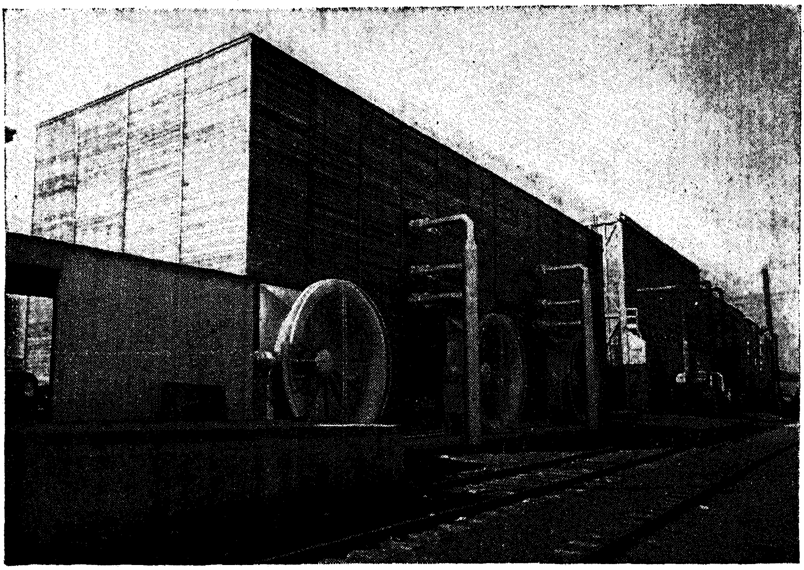


Fig. 1387. Two 16-in. vertical headers, branching off from 36-in. under-ground line and reducing to six 8-inch lines serving spray nozzles in a forced draft cooling tower.

Piping for High Pressure and High Temperature Systems.—When pressure and temperature are both high the advantages of welding are noteworthy. In fact, welding is said to have made possible the use of the high pressures and temperatures now common, resulting in a material increase in efficiency of performance of piping systems. The welded joint is of exceptionally high quality (see Page 262) permitting high operating stresses and thinner sections.

Because of these facts it is necessary that these pressure systems be well designed (see codes Page 132). Stress distribution should be given consideration for both the usual and unusual conditions such as expansion, contraction, external restraint or loading of pipe.

Stress relieving is immediately thought of. However, it should be kept in mind that residual stresses are not necessarily added to the stresses caused by pressure or bending. The thousands of welded high-pressure pipe joints which have not been stress relieved and which are now in service, attest the fact that stress relieving may not be required for perfectly satisfactory service.

As to temperature, the metal (both base and deposited) should operate at high temperature—800° to 1,000° F. Creep and impact characteristics must not be seriously impaired at these high temperatures.

Every day welded joints are being made for operation at high temperatures and high stresses which have high quality, high strength, ductility, impact values and creep values well within the usual limits.

Pipe Joint Layout.—One of the requirements in connection with the field work of laying out a piping system of any size or kind is

an easy, accurate, inexpensive and quick method of laying out the various types of joints.

There are several methods which may be used, these methods being: (1), the use of a fixture; (2), the use of templates cut to accurate dimensions; or (3), method whereby the intersection may be laid out on a pipe directly from curves or data. Before considering these various methods in their order, it is well to note that on all the drawings, and throughout this entire discussion the *actual intersecting line on the external surface is the line given* and that it will be necessary to take into consideration when cutting the pipe, the type of joint. If it is beveled, obviously the intersection line will, of course, be in the center of the bevel. Reference to Fig. 1388 will illustrate this point. Fig. 1388 shows a 90 degree ell. The cutting line is shown dotted and the intersecting line is shown full. It is evident from this that when the pipe is being cut, it will be necessary for the operator to take into account the kind of scarf to be made and to make allowance for this in cutting the pipe to the proper shape. Where it is not necessary to scarf, of course the pipe is cut directly on the intersecting line marked on the pipe.

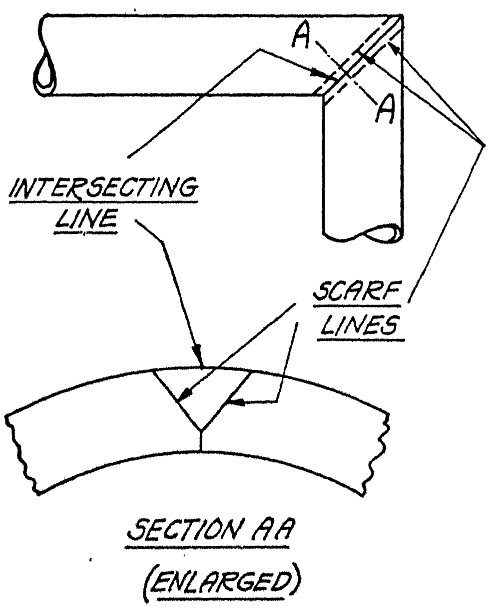


Fig. 1388.

The first method given, that is the method using a fixture, is an exceedingly simple method and can be used in practically all cases. It involves the construction of a suitable fixture, such fixture being indicated in Fig. 1389. This consists of a flexible strap of rather thin material long enough to encircle the pipe and fitted with clamps at

either end to hold it firmly to the pipe when tightened, or to permit the movement or removal when loosened. To this strap a number of smaller clamps are welded at suitable distances apart. A satisfactory number should be selected so as to enable a definite smooth curve to be drawn through the determined points. These small clamps can be square pieces of metal with a hole drilled and tapped and fitted with a setscrew. At right angles to this is another hole through which rods are passed, these rods being parallel to the pipe's center. The setscrew locks the rods in any desired position when tightened or allows the rods to be moved forward or backward.

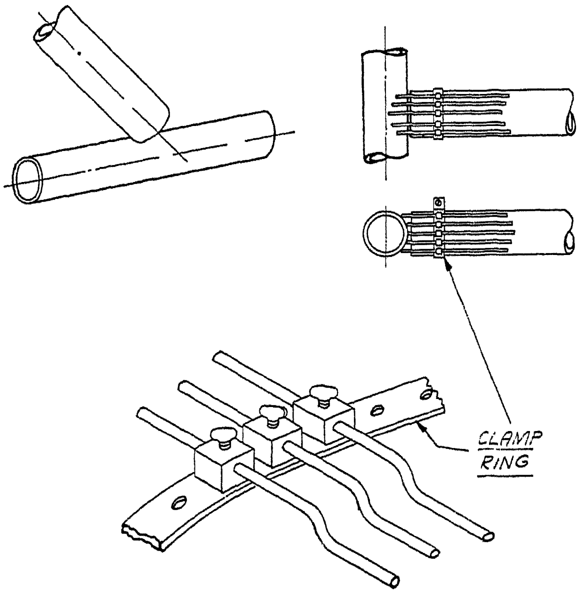


Fig. 1389.

To use this equipment in laying out a connection as illustrated in, for example, Fig. 1389, the strap is clamped around the one pipe so that the ends of the movable rods in the clamp may touch the other pipe to which the connection is to be made. Both pipes are then held in the desired position in relation to each other. The rods are then moved until the end of each rod touches the pipe to be connected. When the ends of all the rods touch this pipe, they are then clamped in position by means of the small setscrews. The curve formed by the rod ends thus simulates the curve of the wall of connecting pipe. The strap holding the assembly to the pipe is then loosened and the assembly is moved back along this first pipe until the end of the rod which projects the farthest is just flush with the end of the pipe to be cut. The line to follow in cutting the pipe is then indicated by marking on the pipe at the end of each rod. This done, the clamp is

removed, the curve completed, and the pipe is cut as indicated. For the other pipe the same process is used of connecting the points marked by the end of the rod. In some cases it may be desired when using this method, to form a template. To do this the strap may be laid out flat on suitable material and a template drawn. This fixture permits the laying out of special connections for practically any size of pipe. A single fixture can be used or several can be joined together to provide the necessary length to encircle the pipe. It is advisable, therefore, to have this fixture in several sections so that various pipe sizes may be fabricated. However, where one size of pipe is being used in connections of varied intersections, a single fixture affords an easy and practical means of laying out the connection, produces a fairly accurate intersection for practically any type of pipe joint and is not expensive.

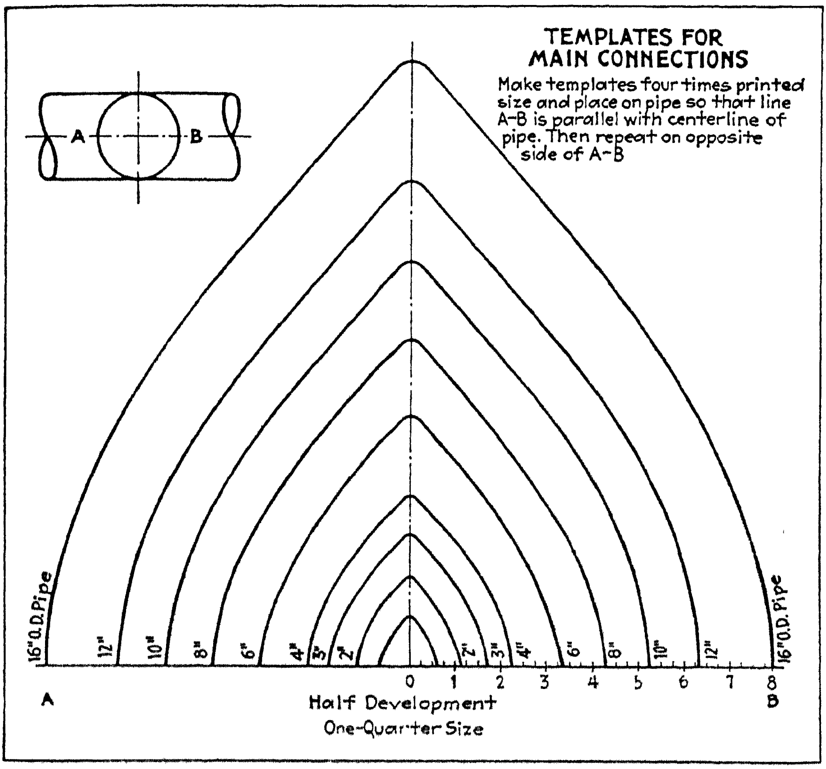


Fig. 1390. Quarter-scale templates for branch connection of a 1-to-1 tee.

The second method, that is the method of using templates, gives the operator an exact curve that can be placed around the pipe's circumference to indicate the precise cutting curve. Fig. 1390 shows the various templates for different size pipe for 90 degree, 60 degree, 45 degree and 30 degree ells. To use this method, a circumference

is drawn on the pipe at a suitable distance from the point of intersection. A duplicate of the proper curve is then taken from Fig. 1390, this, of course, depending upon the pipe size and the angle desired. A template is then made and placed around the pipe in the proper position, on line CD at right angles to circumference. The template covers only one-half of the intersection circumference. The purpose of this is to prevent misalignment due to variation in pipe circumference. The variation is taken at two opposite points on the diameter of the pipe and the variation occurs at the points where the curve is flat and is therefore of no great importance. Reference to Fig. 1390 will indicate how this is done. It should be noted that the scales of

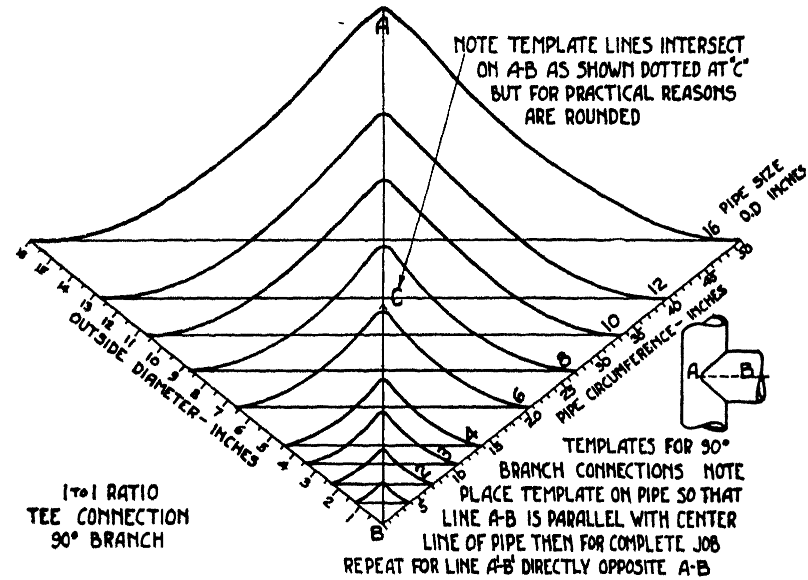


Fig. 1391. Templates for the through run of a 1-to-1 tee.

circumferences in inches are given with each group of graphs. This will enable the operator to approximate any template for any one of the given angles. By using the curve for the proper angle and finding the circumference of the pipe and laying this out in accordance with the scale indicated for this angle connection, a curve may be drawn lying between the two other curves that are similar in shape. The template may be used on any pipe regardless of its thickness, as the data are given for the outside circumference and, in addition to that, the use of one-half of the pipe permits any variation to come at a point where the curve is flat and therefore not of any great consequence.

The same method is used for tees, templates for which are shown in Fig. 1389 and Fig. 1390.

The third method, that is the laying out of joints by means of special curves, possesses great advantages, particularly in the field where special joints are being made. It is faster than the template form and

the only equipment needed is a string and a piece of chalk, with perhaps a ruler or scale. It is, of course, necessary to have the master drawing (Fig. 1391). This one drawing will serve for 90 degree, 60 degree, 45 degree and 30 degree ells for any size of pipe. The general method of application of this curve is to place the string around the pipe and then to divide the string into a half, quarter, eighth, etc., obtaining equal points of division around the given circumference of the pipe for 16 points. Suppose for example, that the operator desires to make a 60 degree ell on a certain size pipe and that he does not know definitely the pipe size. The first step is to find the circumference of the pipe by means of a string wrapped around the pipe. While

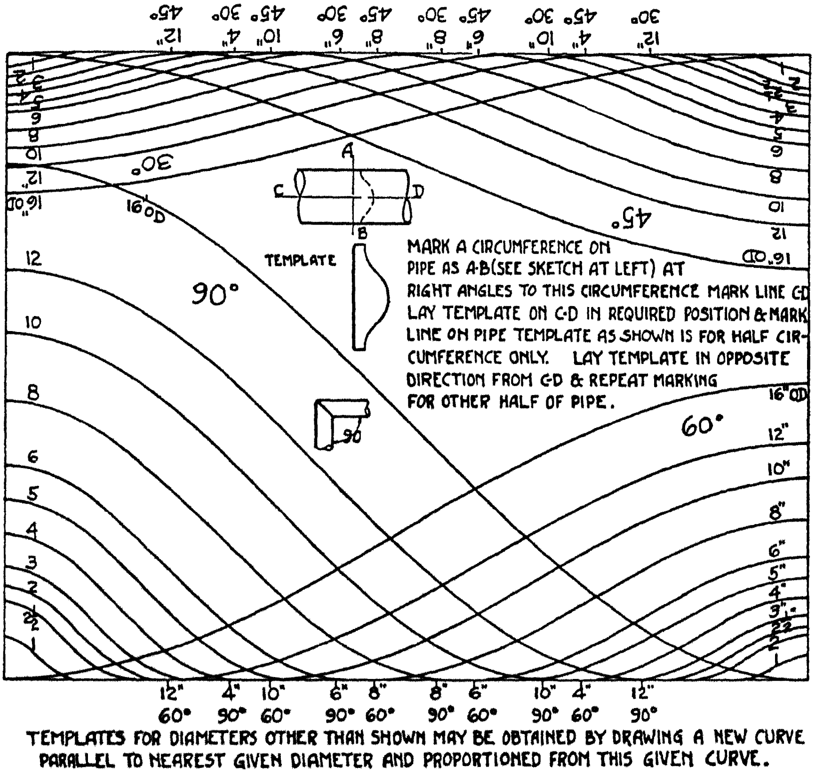


Fig. 1392. Templates give an exact cutting line for ells of 90, 60, 45 and 30 deg.

doing this it would be well to mark off a circumference on the pipe at the proper distance from the ends. The circumference is then divided into two equal sections by doubling the string. By repeating this process of doubling until sixteen parts have been obtained, an easy means of dividing the pipe into sixteenths is procured. These marks are placed around the pipe.

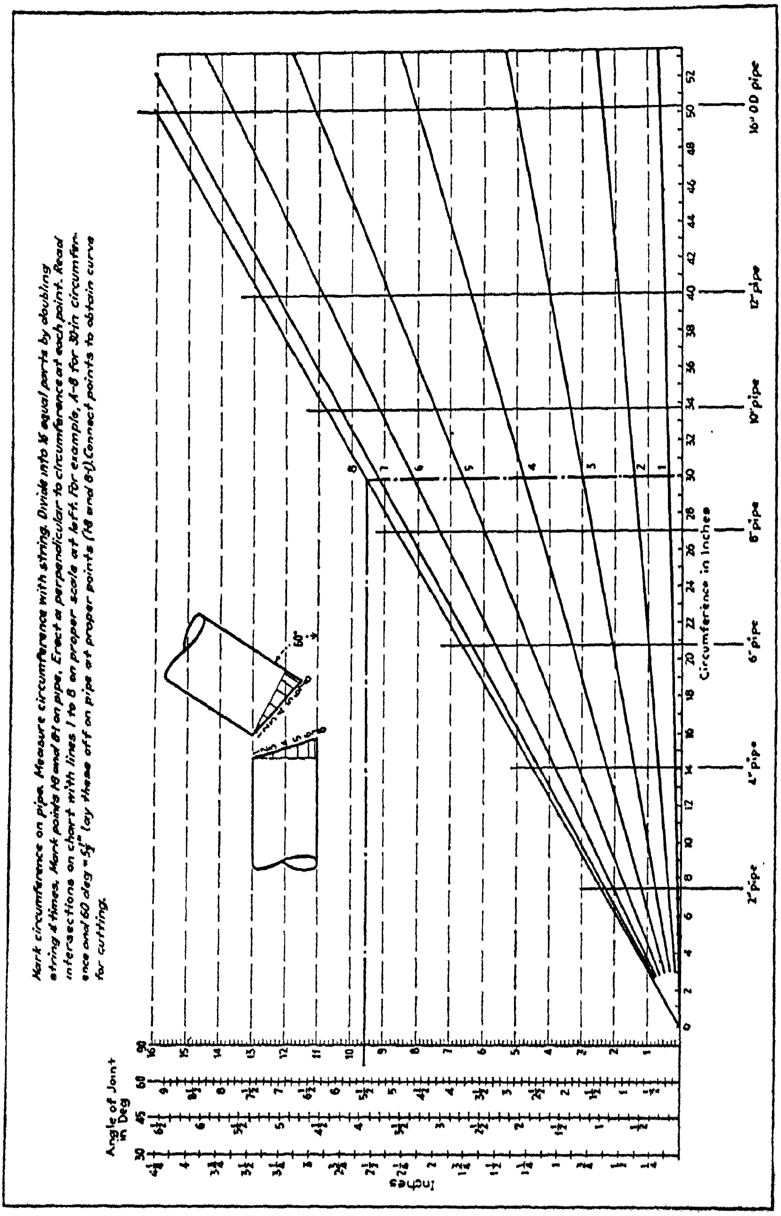


Fig. 1393. With a piece of string, a ruler and this chart, ells can be laid out rapidly by using the eight measurements shown.

Suppose for example, that no measurement is available. Then the string which has been placed around the pipe and from which the circumference has been obtained is doubled and placed along the drawing at a point marked zero. Supposing the distance is just thirty. At this point the string (or ruler if preferred) is placed at right angles to lower border of the drawing and this line intersects on the eight diagonal lines on the graph. Then, the distance to the top line, that is, to intersection A, is marked off on a paper or measured by the string, and this distance is then carried over to the column marked 60 degree ell, and we find this to be five and one-half inches. This point is then marked off or measured off by the rule at one of the sixteen points, the dimension being made perpendicular to the circumference. If no scale or rule is available, the length may be converted to inches by using the 90 degree ell scale, which is full size and in this way obtain a measurement of the point number eight. The same process is then carried out on points seven, six, five, four, three, two and one, these being laid out in order on eight of the sixteen points, the dimensions being made perpendicular to the circumference on the pipe. It should be noted that inasmuch as this is a symmetrical curve, it is relatively easy to start with one line perpendicular to the circumference which might be termed the zero line and mark point eight on both sides of this; then point seven on both sides of this, then six, and so forth. By continuing this process through all eight lines, the sixteen points on the pipe surface that represent the cutting curve, can be obtained. When connected, these points give the curve on the surface—which is the intersecting curve—and guide the operator in scarfing as indicated in the first part of this discussion.

The same process is applicable to the cutting of any of the other angles as shown in the group of scales at the left of Fig. 1086. The method is convenient, covers any size diameter up to 16 OD or a little larger, on this particular graph. It permits the construction of the curve on the pipe with a minimum of materials and labor.

A more general application of this method is shown in Fig. 1394. This gives a graphical means of determining the layout of pipe intersections for any angle of ell type of connection. As in the method just outlined, the sixteen distances are found and are located as indicated previously by means of measuring the circumference of the pipe with the string, doubling it, repeating the process until it has been divided into sixteen parts. Then, the method is as follows:

Assume for example, that we desire to lay out a 45 degree ell on a 10-inch pipe. Then at 45 degrees as at A, we get the intersections of the lines one to eight inclusive. These we will refer to as ratio lines. The points of intersection of this line A-8 with lines one to eight, are projected at right angles to the ratio line and continued until they intersect the line for 10-inch pipe diameter. Then, by progressing downward on the graph, the dimensions are obtained. Then they are laid off in the same manner previously applied.

Although this is rather simple, it is superior to the preceding one, in that it affords a means of determining ell cuts for any degree of bend. It is important to note that the pipe diameters are the external

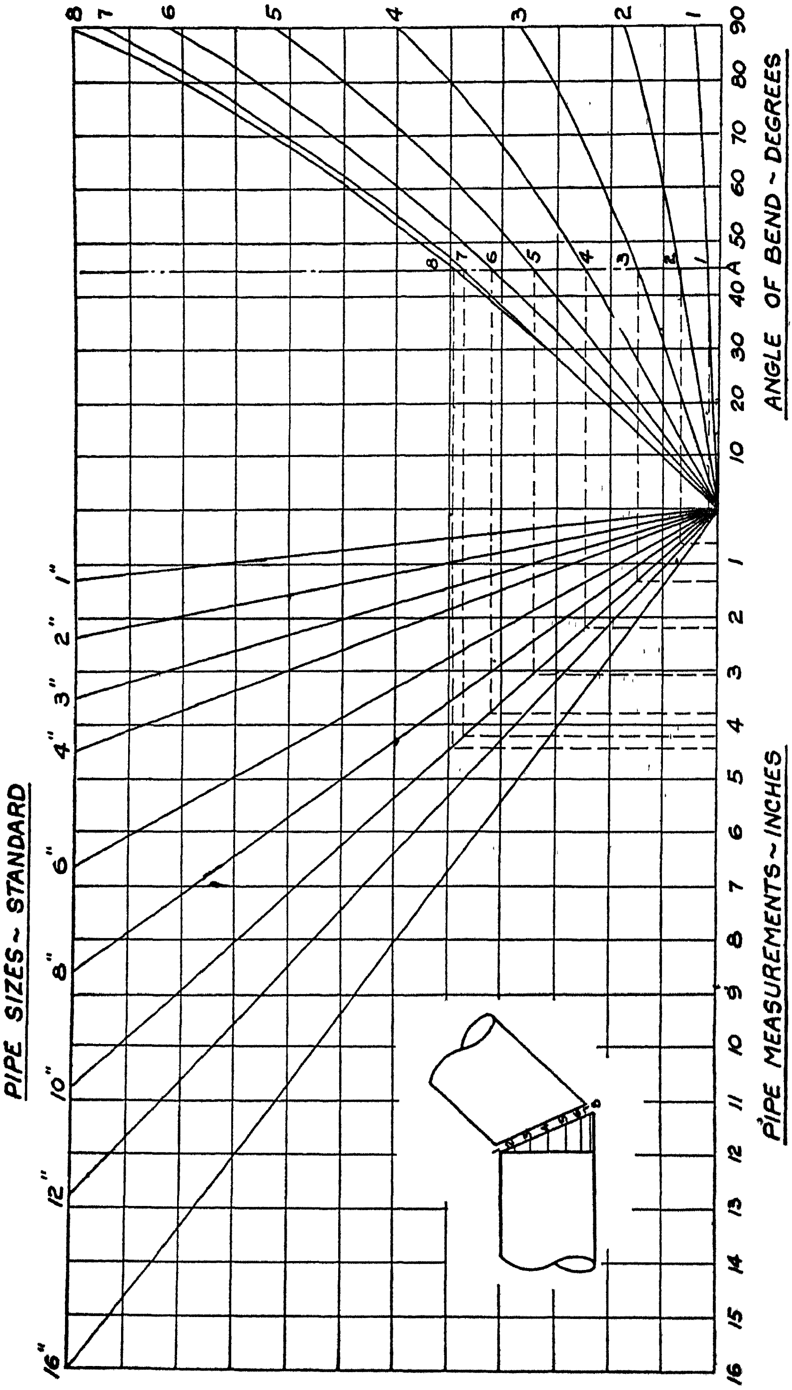

PIPE SIZES ~ STANDARD
1" 2" 3" 4" 6" 8" 10" 12" 16"
ANGLE OF BEND ~ DEGREES
10 20 30 40 50 60 70 80 90
A
PIPE MEASUREMENTS ~ INCHES
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Fig. 1394.

diameters and that the intersections are for the actual intersection line. Of course, additional information can be added to this drawing by reference to Fig. 1393.

Templates for a one-to-one ratio tee connection, that is, where both pipes are of exactly the same diameter, are shown in Fig. 1391 and Fig. 1392. These templates are drawn so that tee templates may be added between the given curves for any size desired. It is relatively simple to draw a curve between any two curves at the proper point of a given scale, the curves being similar to the curves shown. It is to be noted that these are for a one-to-one ratio, that is, for pipes of

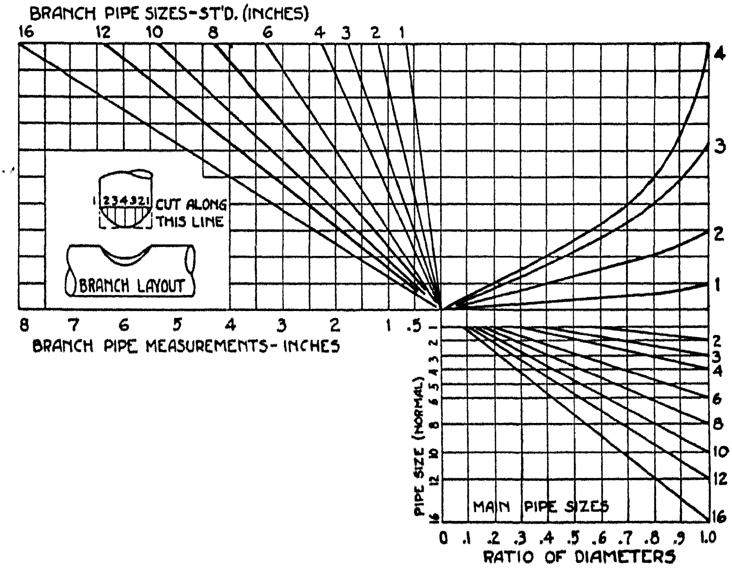


Fig. 1395.

the same diameter. However, when the ratio of pipe diameters is different, that is, not one-to-one, the problem of laying out these intersections is somewhat more difficult.

On Fig. 1395 and Fig. 1396 intersection curves are given for tee connections for any ratio of pipe diameters. Fig. 1395 and Fig. 1396 are similar in graphical form to what has been indicated for the ell connection. As shown on the templates, each half development is made up of two similar curves, hence only four points or lines are shown. The four curves show points for one-fourth of the pipe circumference. As in the case of the ells, the branch pipe is divided into sixteen parts, the four points giving values for one-fourth of the pipe.

For the branch pipe the method of layout is the same as for the ells. However, for the main pipe, the method, while being similar, is not exactly the same.

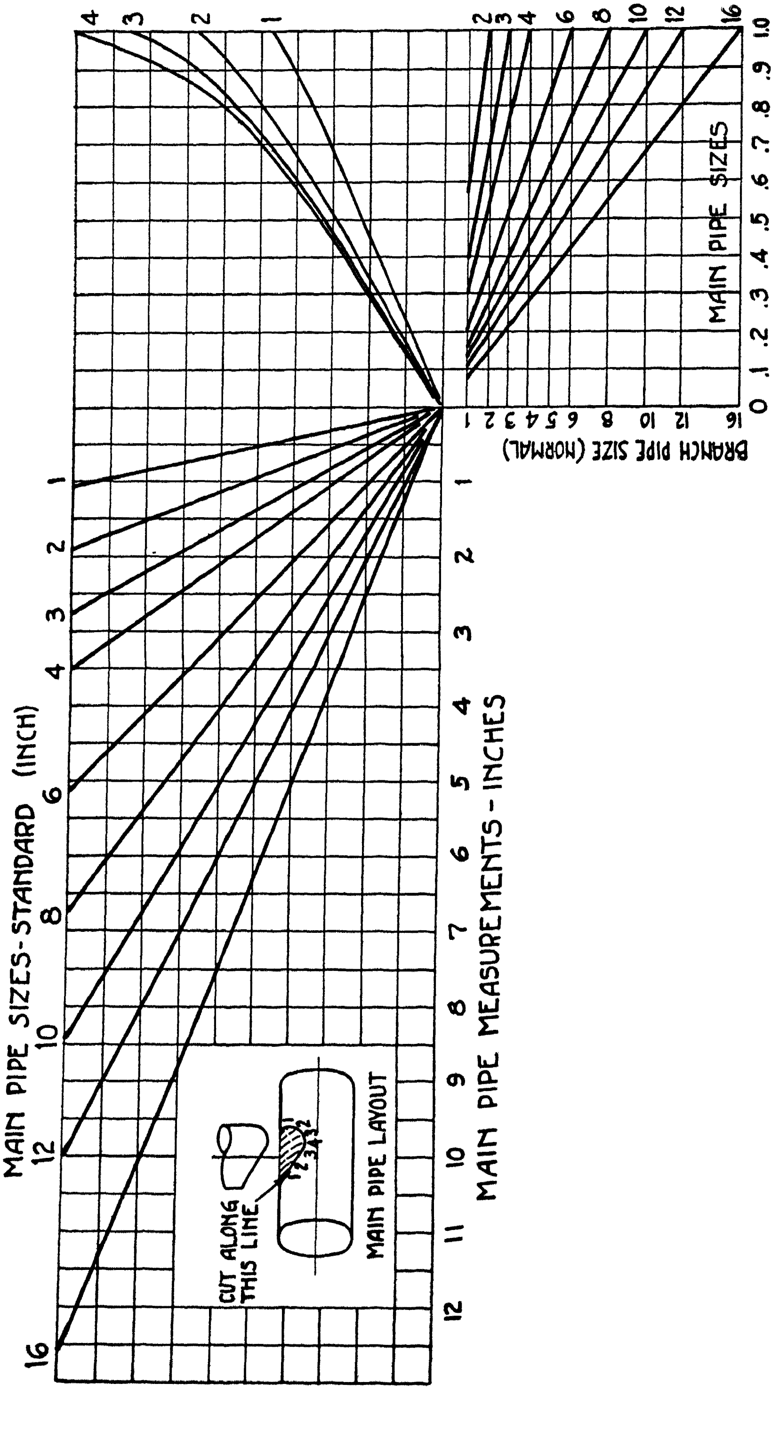
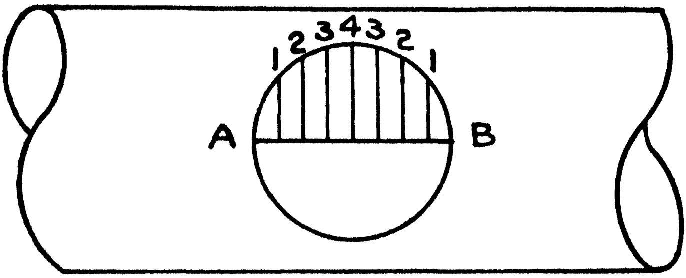

MAIN PIPE SIZES-STANDARD (INCH)
MAIN PIPE MEASUREMENTS - INCHES
MAIN PIPE SIZES
RATIO OF DIAMETERS
BRANCH PIPE SIZE (NORMAL)
CUT ALONG THIS LINE
MAIN PIPE LAYOUT

Fig. 1396.

Reference to Fig. 1397 will show what is meant by the intersecting diameter. It is the diameter of the branch which lies on the main pipe and is parallel with the center line of the main pipe. This intersection diameter is located on the main pipe at proper position.

Curve, Fig. 1396, is used where the intersecting diameter of the branch is drawn on the main line. This diameter is divided equally into eight parts and the four points, one, two, three and four, are used as shown in Fig. 1397. The actual measurements may be taken from the graphs as they are full size. It should be noted that all measurements in this graph are on *circumferences* of the main pipe, that is, on lines at right angles to the intersecting diameter.



LINE A·B IS INTERSECTING DIAMETER

Fig. 1397.

Pulp and Paper Mill Equipment

The extent of arc welding application in the modern pulp and paper mill is illustrated in the case of a 150-ton pulp mill built recently in Southeast Texas. In the first place, plant equipment and structures built by other manufacturers and contractors are largely of welded steel construction. This equipment includes large storage tanks, mill machinery, smoke stacks and many structures. During construction of the mill, approximately twenty arc welding machines were in constant use erecting steam lines, water lines, stairways, conveyors, mill frame work, machine and motor bases, machine guards, cutter boxes, stainless steel chutes, racks for electric conduit, etc. Since the mill has been in operation, four arc welding machines have been used for maintenance and construction applications.

The following illustrations show typical arc welding applications in this modern mill.

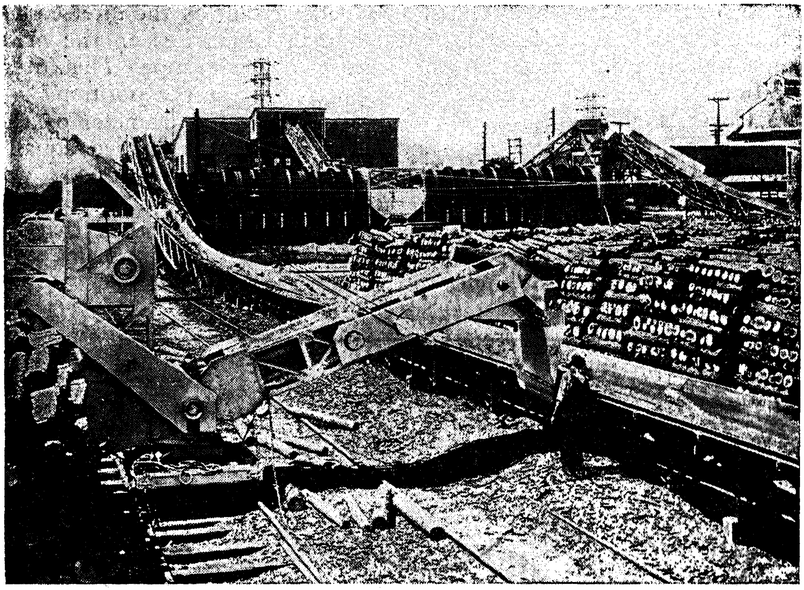


Fig. 1398. Equipment in the log department is subjected to severe service conditions. Much of it is of arc welded steel construction in order to best resist constant battering and fatigue stresses.

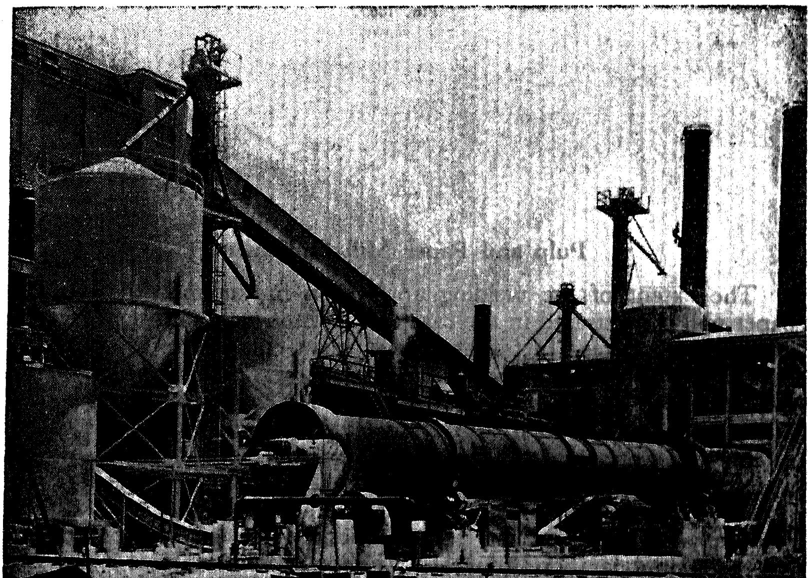


Fig. 1399. View of the section of the mill where considerable mechanical operations are involved. Storage tanks and bins for lime, water and other chemicals are of welded steel construction to provide permanent tightness of joints and maximum resistance to corrosion.

Fig. 1400. This welded steel stairway built from channels, angles and plate is typical of the construction used throughout the plant. The large storage tanks shown in the background are also of arc welded construction.

Fig. 1401. Welded water and steam lines in a power house. The majority of the pipe throughout the plant is of arc welded construction.

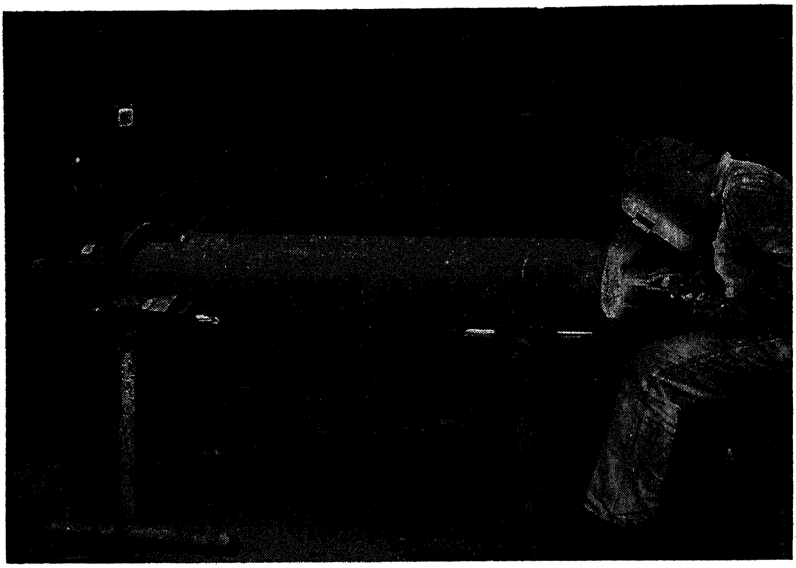


Fig. 1402. Replacing the inner wall of smelter blow nozzles by arc welding. These nozzles are subjected to severe corrosive conditions caused by combination of high heat and caustic chemical. The inner wall is being replaced with a section of wrought-iron pipe welded in with three passes of 3/16-inch mild steel electrode.

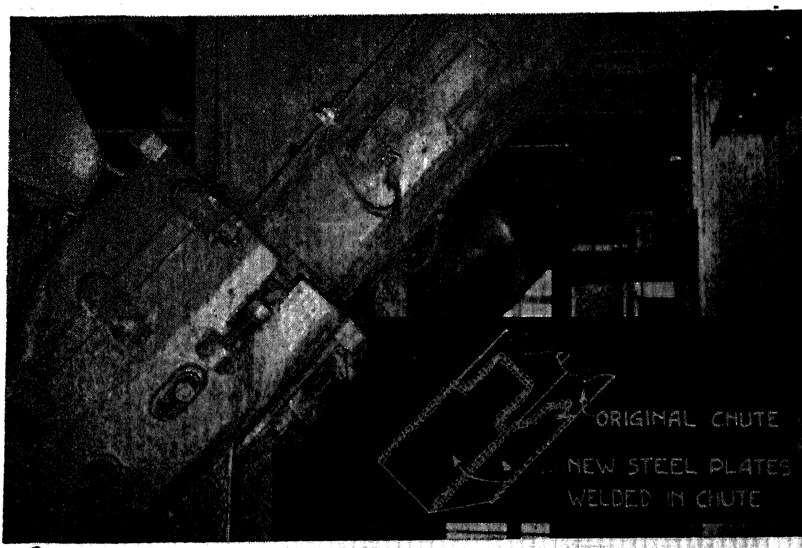


Fig. 1403. When log chipper chutes are broken due to fatigue from severe and constant vibration, a new lower section, cut from high tensile steel, is welded in as shown in the sketch. The irregular line of the weld is claimed to be stronger than a straight cut.

Railroad Equipment

Great strides have been made in recent years in the application of welded steel to the construction of railroad equipment. Of special note is the use of low-alloy, high-tensile steels with welded fabrication, resulting in minimized dead weight and increased economy of operation. In these designs, arc welding plays a prominent part. See Fig. 1405.

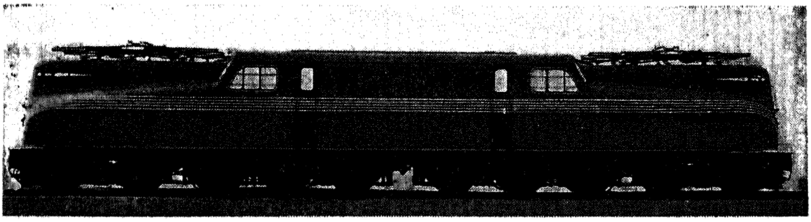


Fig. 1404. Arc welded cab on electric locomotive.

Not only is arc welding being used extensively by the builders of railroad equipment but it is used widely by the railroads themselves. In fact, the railroads have always been one of the largest users of electric arc welding. In the boiler shop, arc welding is used to add new side, crown, door, throat and flue sheets as well as flues and thermic siphons. Since high ductility, density and strength are required throughout the boiler, most of this welding is by the shielded arc process.

Shielded arc welding is also used to a great extent in locomotive shops in the repair of frames, wheels, cabs, etc. The cab shown in Fig. 1404 is of all arc welded construction. Cracked frames (see Fig. 1417) and rims and spokes of wheel centers are also arc welded. Worn rims are also built up by the manual and automatic arc welding processes. Where more than one hundred sets per year are to be refaced, automatic shielded arc welding is recommended for maximum economy.

Railroad machine shops, too, employ arc welding for a wide variety of maintenance applications. Much of this work consists of the building up of worn surfaces of parts such as cross head guides, driving boxes, link sections and parts, shafts, brake fulcrums, cams, coupler parts and guide bars. A few typical applications are illustrated in the following pages.

Arc welding is also being used more and more extensively in the construction of locomotives (see Figs. 1404 to 1415).

In the car shops, arc welding is used to apply reinforcing plates, bars or straps to weakened portions of the car body and underframe. Equalizer ends become badly worn after extensive service. These are built up to original dimensions by welding additional metal to them with the electric arc.

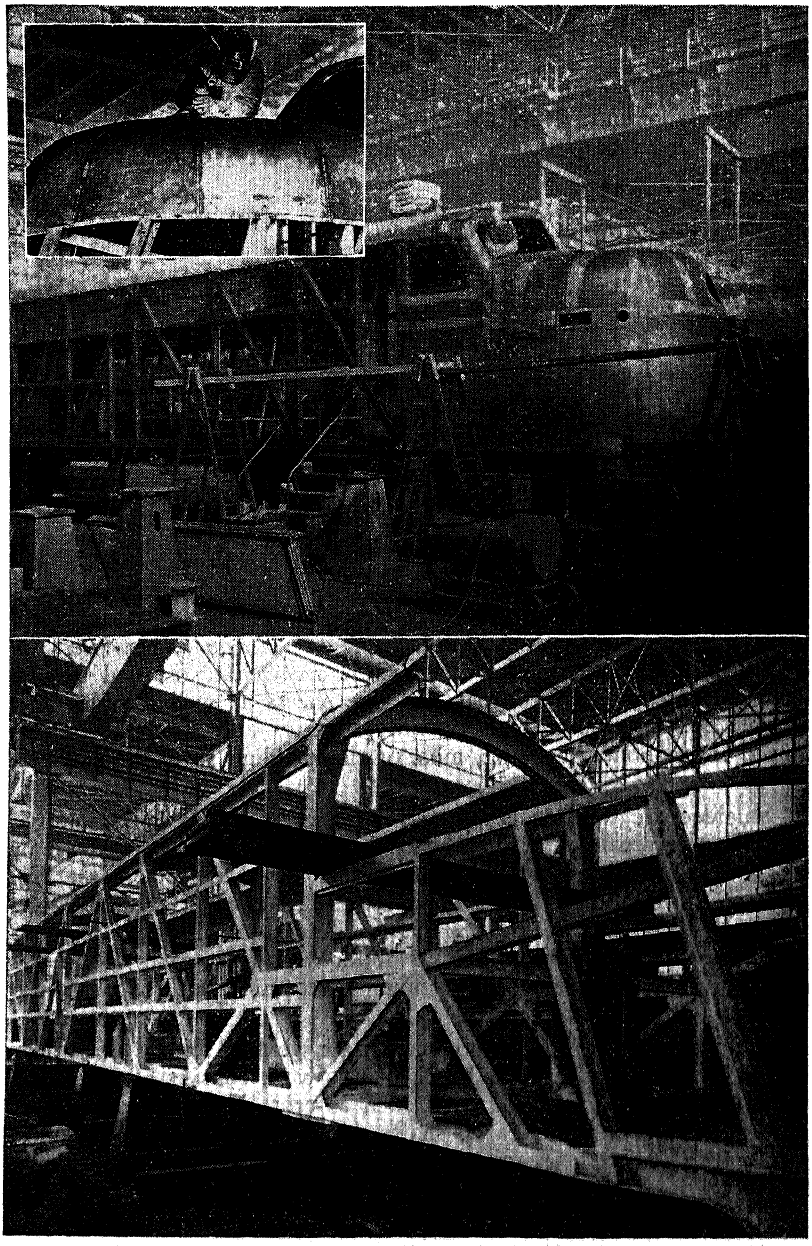


Fig. 1405. Popular Diesel electric streamliner locomotive under construction. Welded high tensile steel minimizes weight per unit of power output, reduces cost, enhances appearance and results in safer, more economical operation.

A large public utility company which owns and operates a great number of steel gondolas has completely rebuilt the underframes and bodies of many cars entirely by the arc.

The arc welded hopper cars shown in Fig. 1414 and Fig. 1415 illustrate construction that is typical of the thousands that are being designed for arc welding. Note the smooth interior surfaces for efficient unloading of materials.

Maintenance-of-way applications include the building up of worn frogs, crossings, switch points and rail ends. Welding machines for these applications are usually designed for easy de-railing, and are either towed by a speeder or are self-propelled.

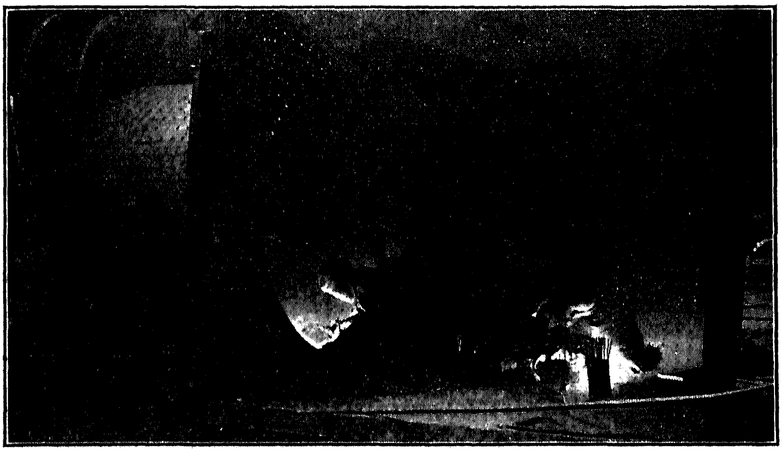


Fig. 1406. Side seams being welded in fire box in the construction of locomotives.

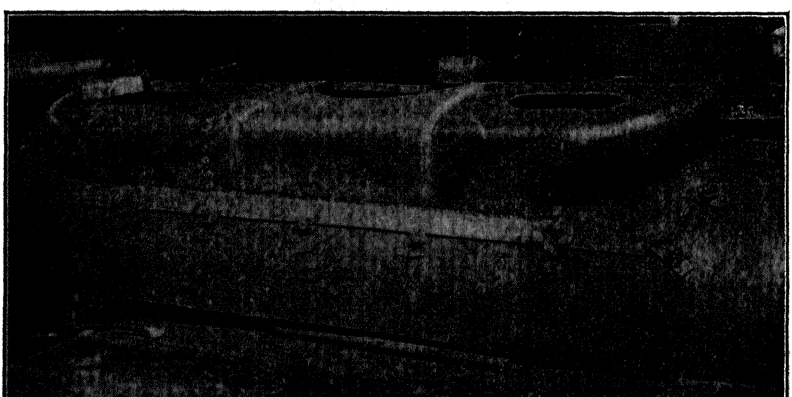


Fig. 1407. All-welded locomotive sand box. Note how it is clamped to a fixture for welding.

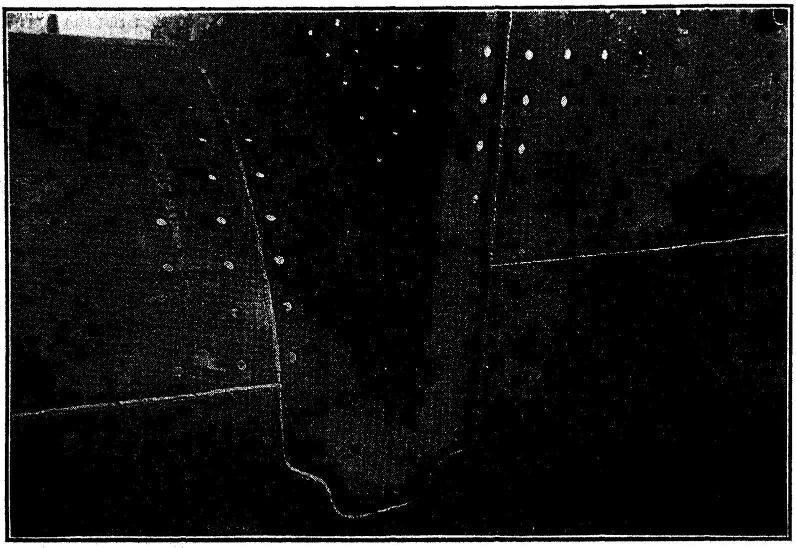


Fig. 1408. Locomotive firebox completely welded by shielded arc process.

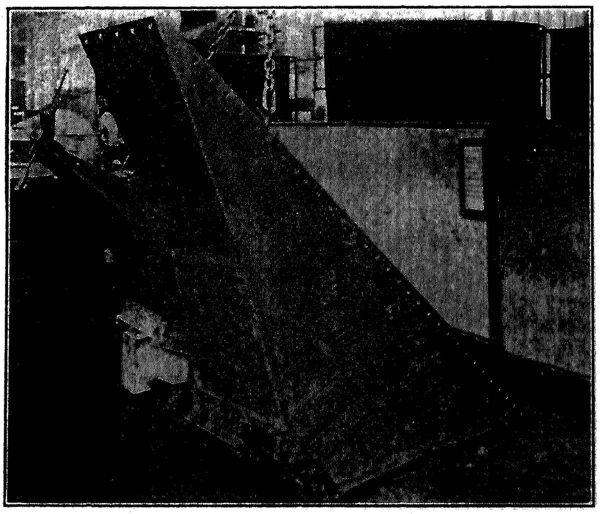


Fig. 1409. Locomotive ash hopper fabricated by the shielded arc process.

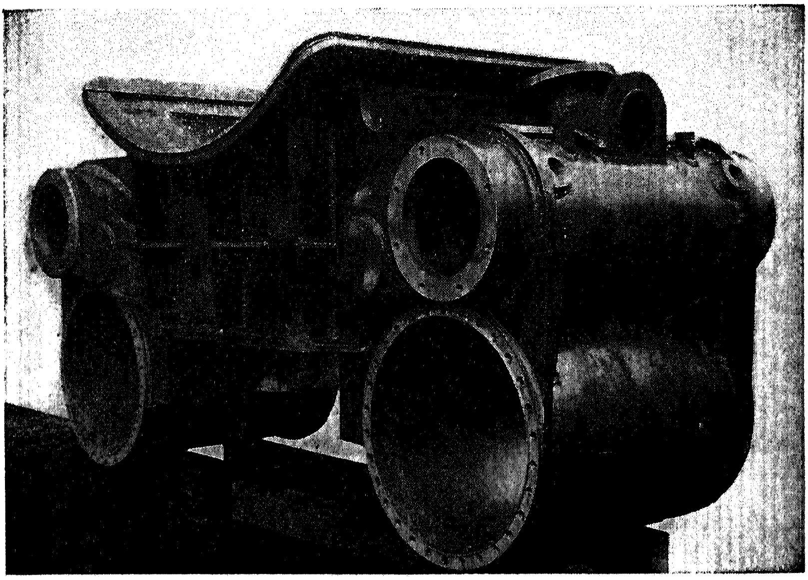


Fig. 1410. Locomotive cylinder for mountain type locomotive. Advantages: Exceptional strength and rigidity with minimum weight.

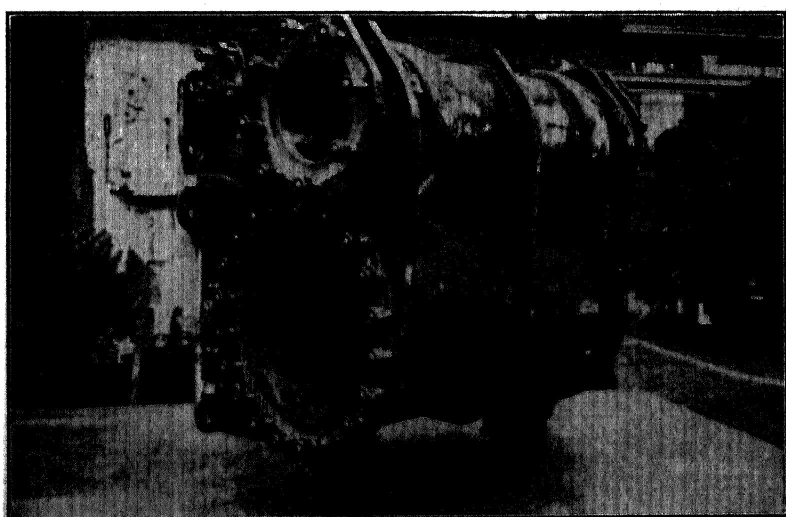


Fig. 1411. Outside locomotive cylinder built in England. This cylinder has now been in service more than 2½ years.

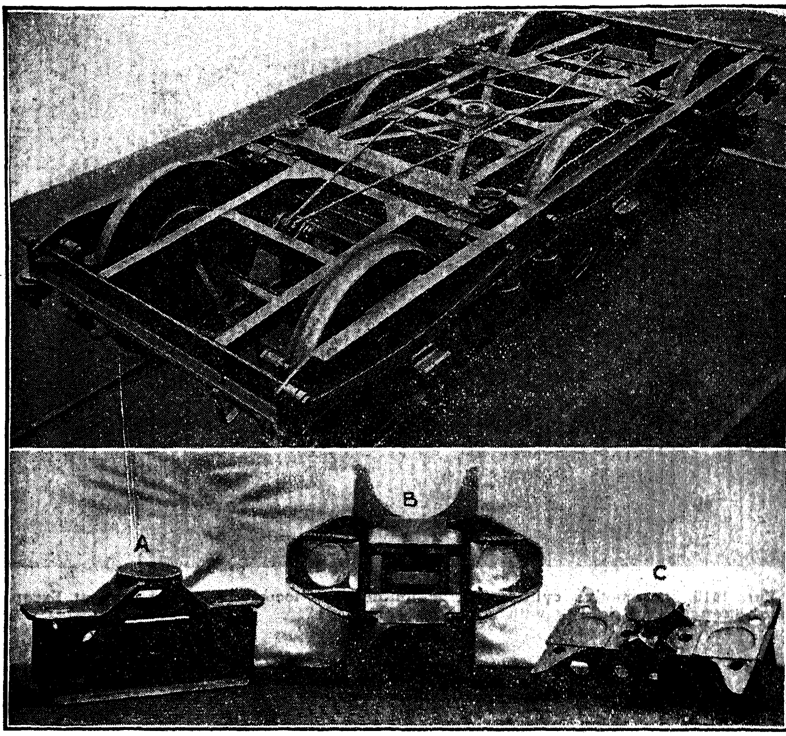


Fig. 1412. Locomotive parts fabricated in England. Top view shows all-welded six-wheel carriage. Bottom view shows boggie center frame stretcher and pony truck center frame stretcher. These parts were fabricated by welding at a saving of 30 per cent over riveting.

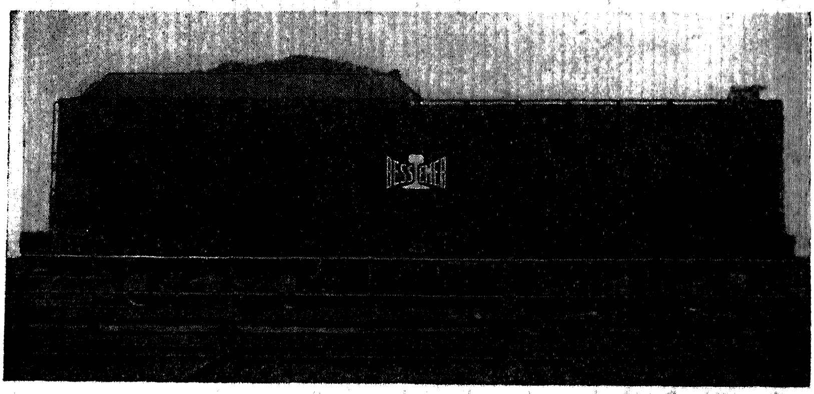


Fig. 1413. All welded locomotive tender.

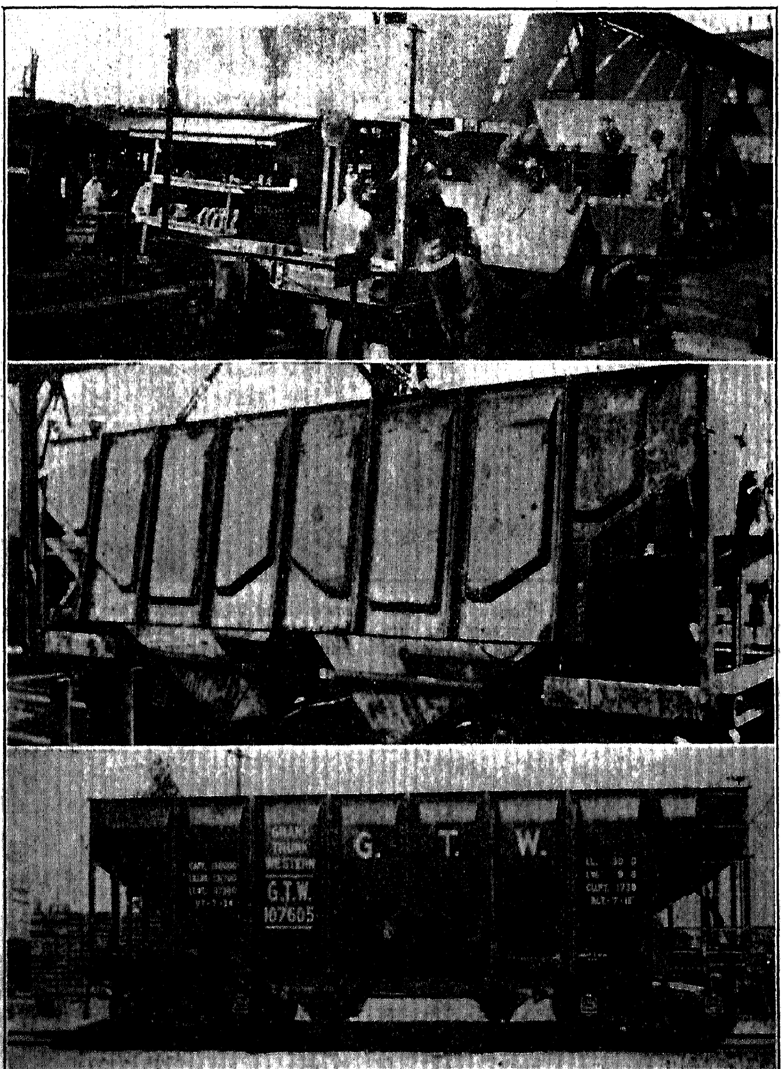


Fig. 1414. Rebuilding 50-ton hopper cars by arc welding. Top view shows assembly operations preparatory to applying side units. Center view shows an all arc welded steel panel section being raised into position. The bottom view shows the completely rebuilt car.

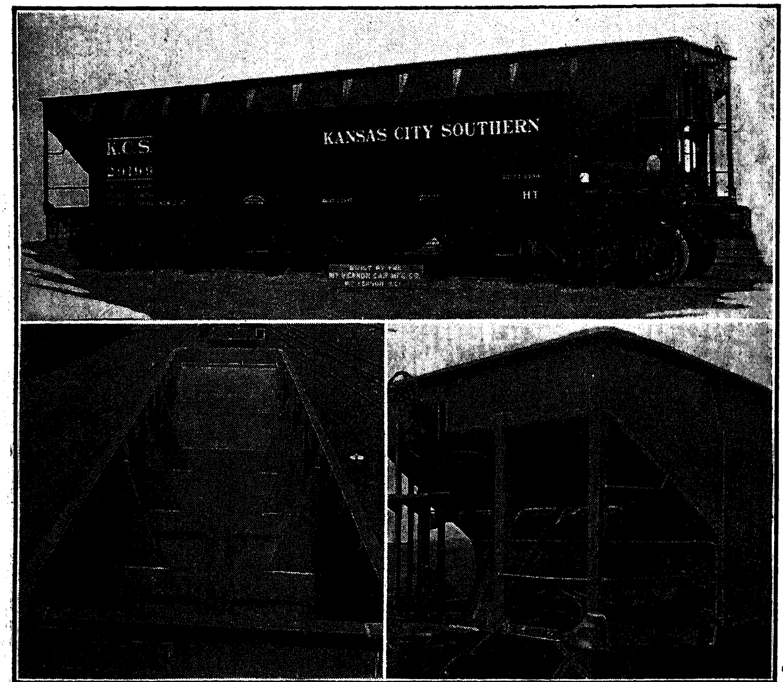


Fig. 1415. Top: 70-ton, quadruple hopper car weighing 54,000 lbs. The manufacturer builds between three and six cars per day. Lower left: Interior view showing smooth surfaces devoid of rust pockets. Lower right: End view of hopper car.

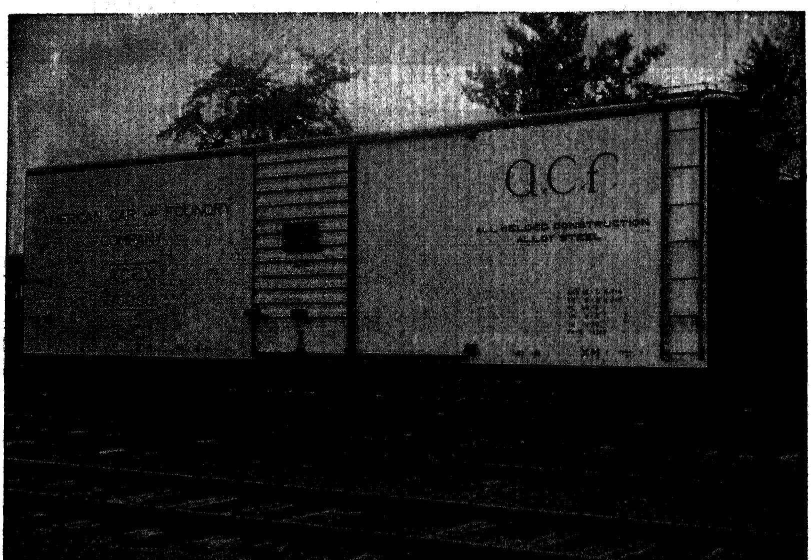


Fig. 1416. A box car of arc welded steel construction. Use of low alloy high tensile steel assures minimum dead weight and maximum pay-load capacity.

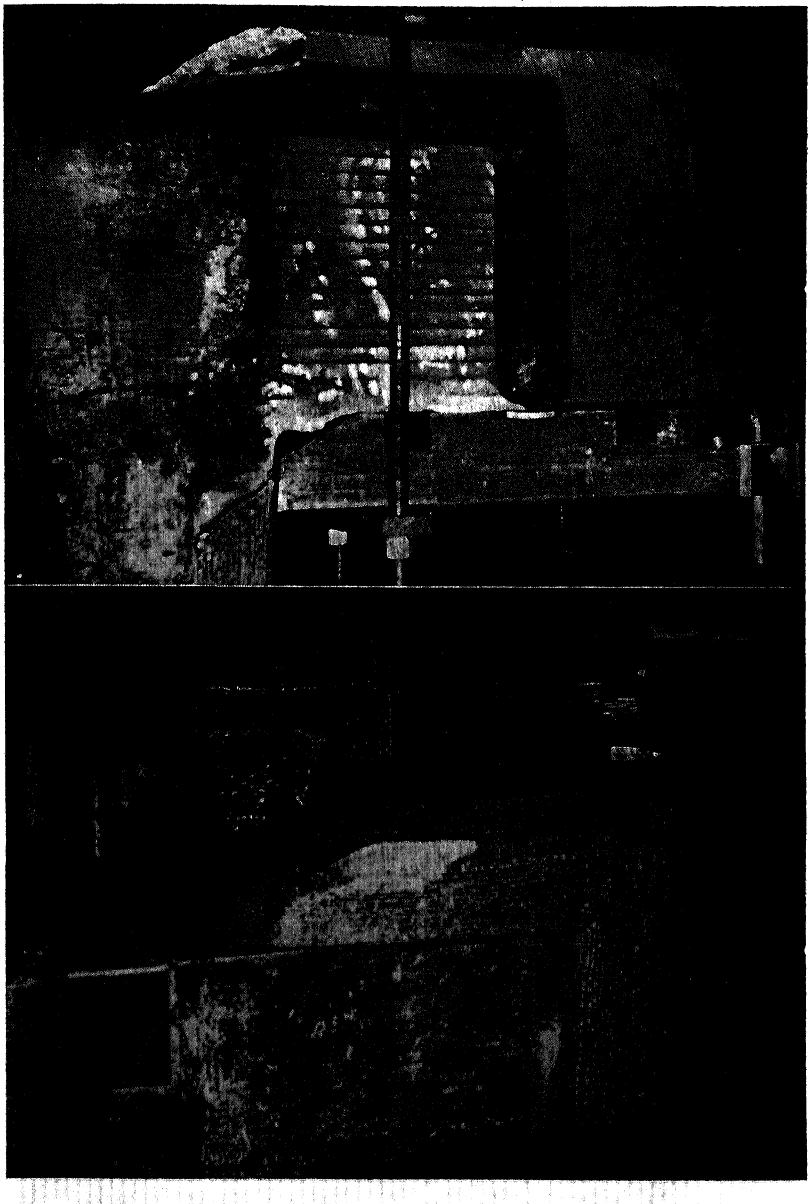


Fig. 1417. Replacement of front frame section of a locomotive by arc welding. Above: Work scarfed to provide maximum weld penetration. Below: Close-up of the finished welds. Required 77 man-hours, 170 pounds of shielded arc electrode. Allowed 1/8-in. for shrinkage during welding and resulted in perfect alignment. Used three operators at the same time, one on each side and one in the middle to keep the heat well balanced at all times. Vertical welds were made by weaving and finished off with stringer beads. Horizontal welds were made with stringer beads entirely.

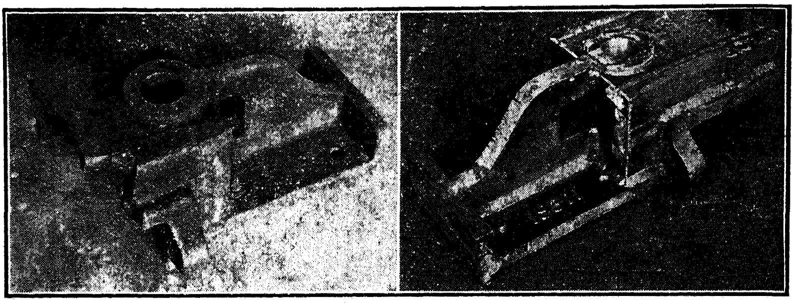


Fig. 1418. When the cast steel locomotive draw head shown on the left broke, it was replaced with the fabricated steel draw head shown on the right. The welded steel part was built complete in 16 hours.

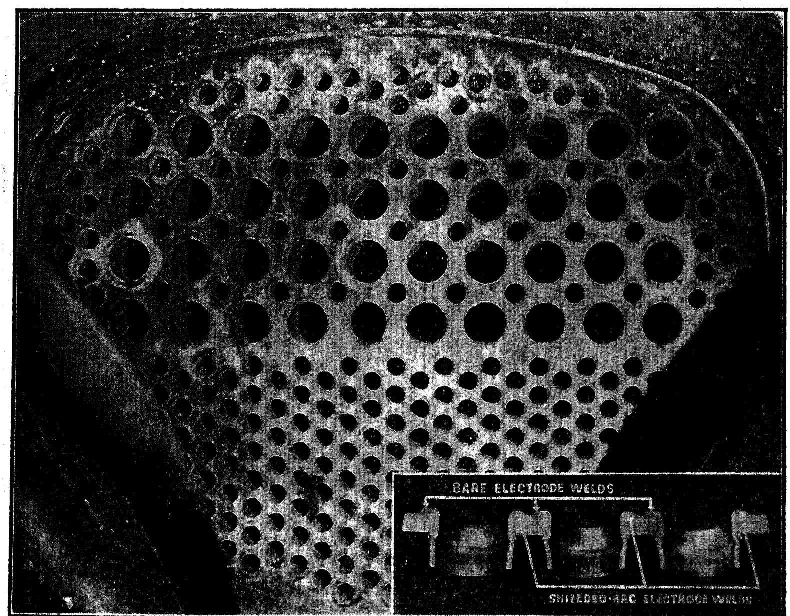


Fig. 1419. A set of locomotive boiler flues welded to back flue sheet by shielded arc welding. The inset shows a test specimen with the welds on the left-hand half made with bare electrode, and those on the right-hand half made with shielded arc electrode. The latter beads are denser and hence more resistant to corrosion.

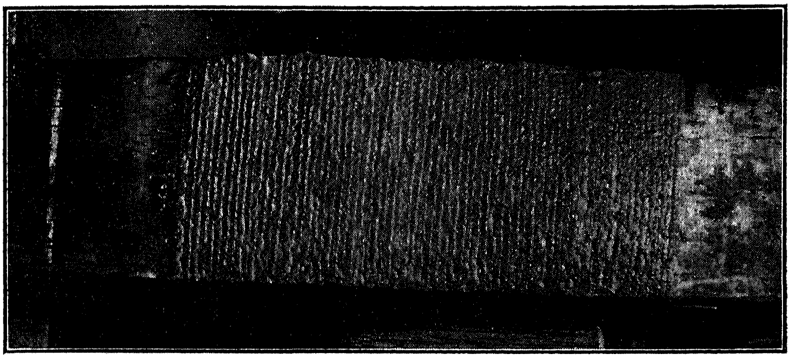


Fig. 1420. Worn locomotive buffer casting after being built up by shielded arc welding.

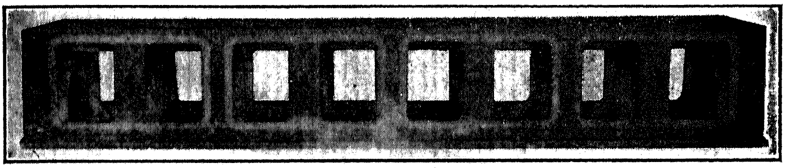


Fig. 1421. An aluminum Diesel engine bed repaired by arc welding, saving approximately $1,100.00

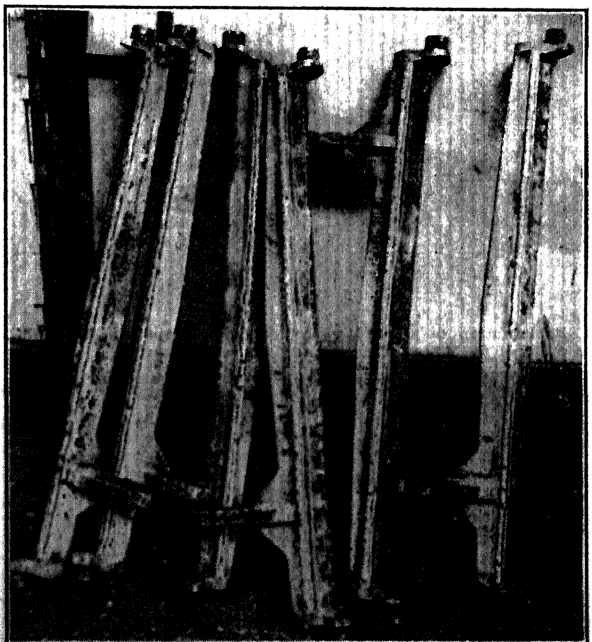


Fig. 1422. Old type unit shaker bars salvaged by building up worn edges with shielded arc electrodes.

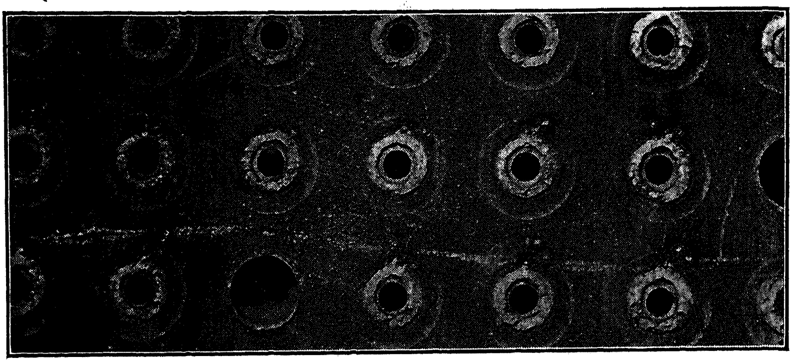


Fig. 1423. Method of renewing locomotive staybolt holes by welding in tapered bushings.

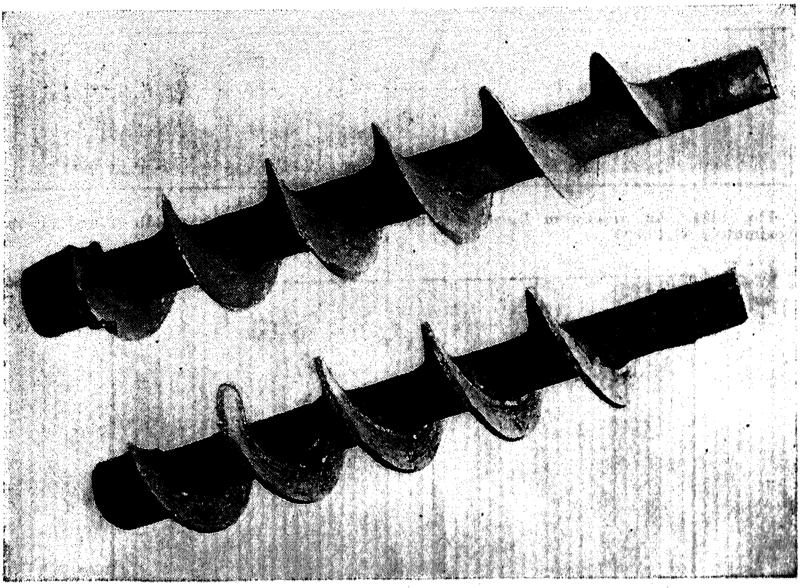


Fig. 1424. Reclamation of worn locomotive stoker screw flights. A metal strip is welded to the edge of the screw, then the face is hard-surfaced.

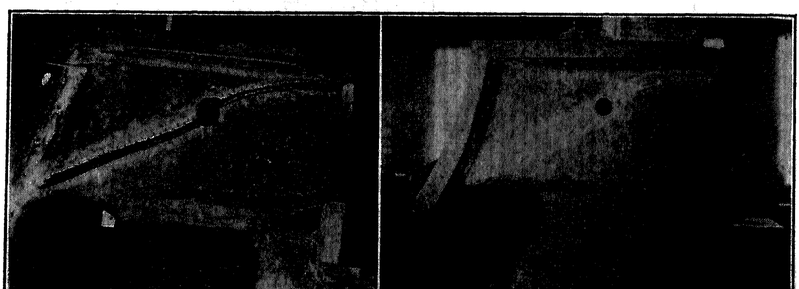


Fig. 1425. The 3-ft. crack in this cast iron locomotive cylinder was repaired by arc welding. The crack was vee'd out and studded as shown on the left.

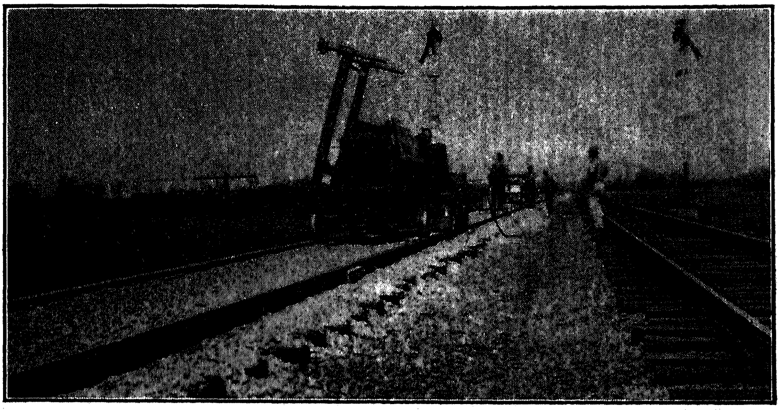


Fig. 1426. Building up battered rail ends on the main line of a Class 1 railroad. The welder supplies electric power for welding and for grinding.

Fig. 1427. The maintenance truck, including a d.c. motor driven arc welder which is powered from the trolley, simplifies track maintenance for the electric railway of a large eastern city.

Rock Products Plant Equipment

The very nature of rock products production is such as to call for extensive use of arc welding for maximum economy. In the first place, the average rock products plant is of more or less temporary location. For this reason, many operators find that they can erect their plant structures and install the necessary equipment at decided savings by cutting and welding at the plant site. This eliminates the expense of detailing, punching and riveting with the conventional steel construction. Moreover, it provides structures which are exceptionally rigid, strong and of light weight. Typical applications along this line are shown in Figs. 1428 to 1432.

Obviously, arc welding is also used extensively in the maintenance of rock products plant equipment, repairing broken parts and reclaiming worn parts. A number of these typical applications are shown on the following pages.

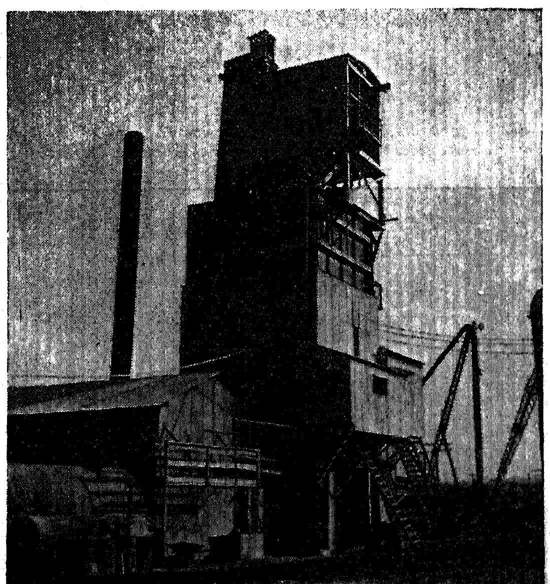


Fig. 1428. Black top plant. The main structure, stairways and chutes are of all welded steel construction, laid out by the company engineer and welded by the plant welder. All steel in standard shapes and sizes was shipped direct from the mill, laid out, cut, fabricated and erected during the slack winter months, saving hundreds of dollars over the cost for riveting.

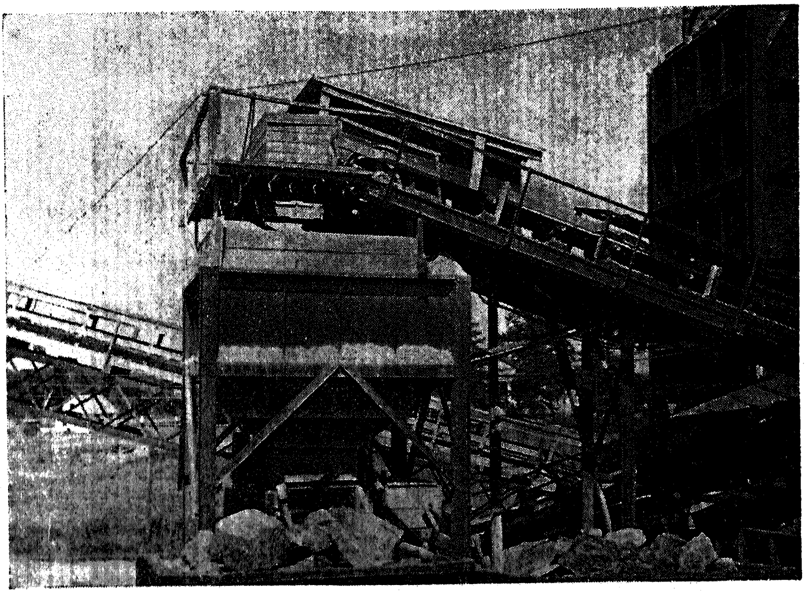


Fig. 1429. General view of a grading plant showing bins and structures of welded steel construction.

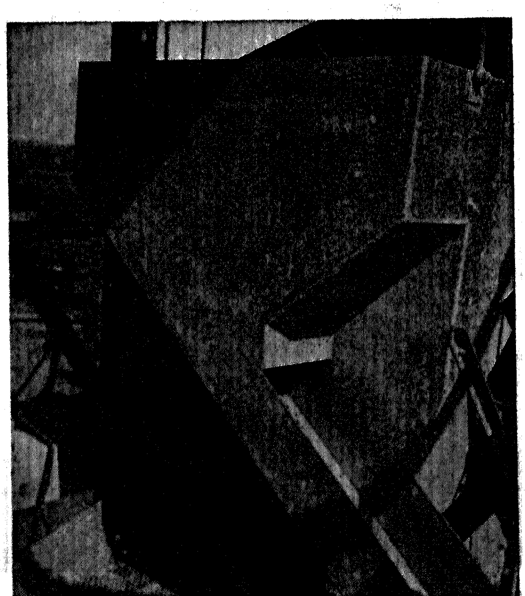


Fig. 1430. Welded steel hopper and chute feeding a shaker screen. Equipment such as this is flame cut and welded right on the job.

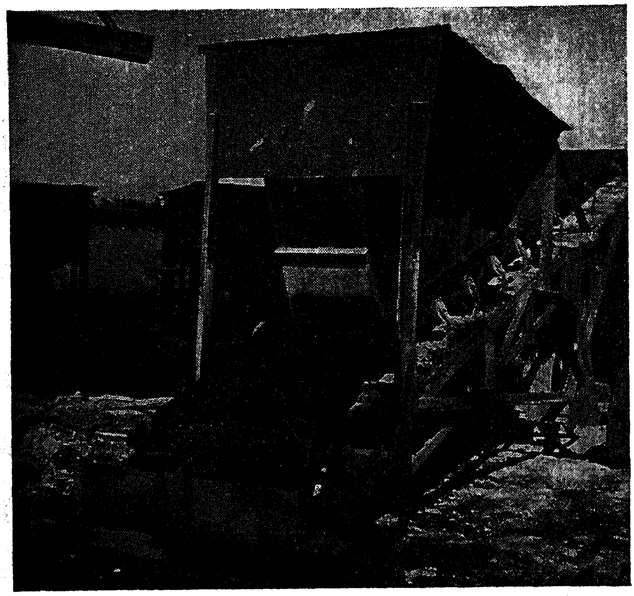


Fig. 1431. Loading machine used at the black top plant. This piece of equipment was built by the maintenance department using standard angles and plate cut to size and joined by arc welding.

Fig. 1432. Chute of a gyratory crusher. It is subjected to severe impact and abrasion. The worn plates are built up and hard-faced to last two or three times their normal life by over-laying them with super abrasion resisting electrode. The plates are removed from the chute and welded during the slack season.

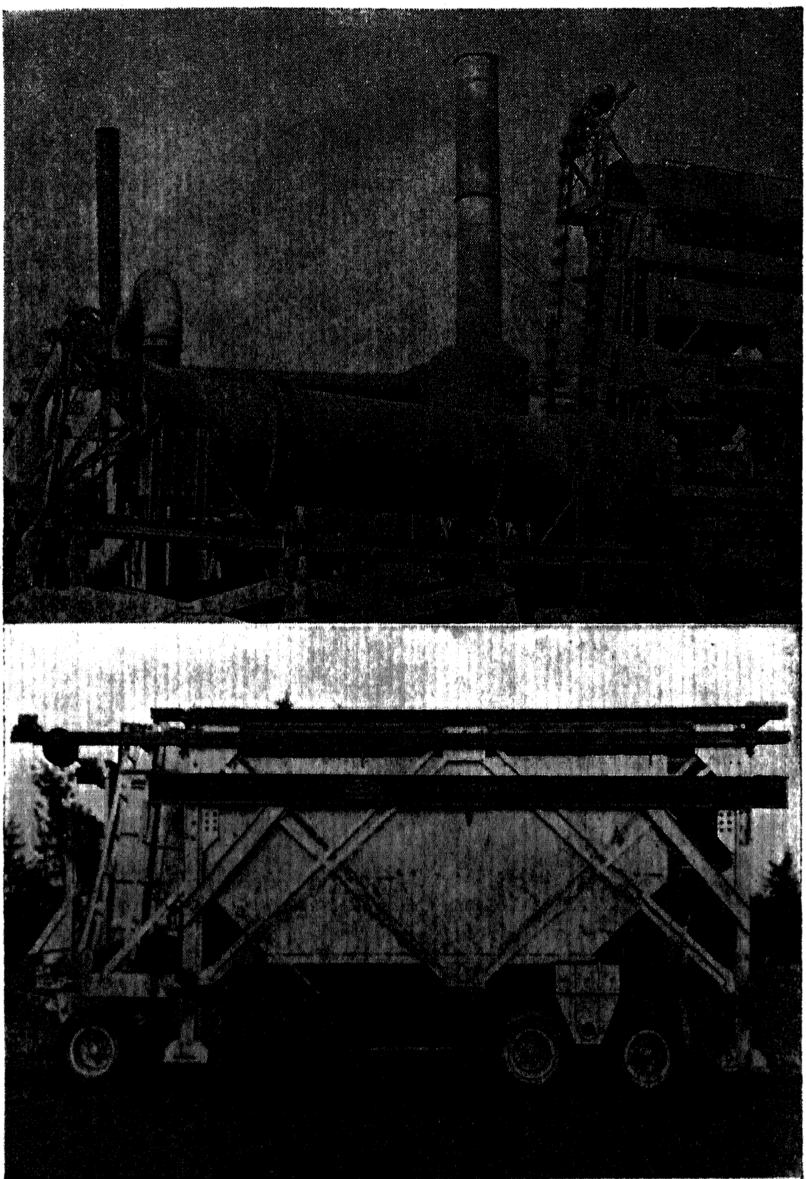


Fig. 1433. Mobile arc welded asphalt paving plant in operation. One of three units, comprising collapsed bins and tower sections is shown below. Welded construction made this unique design practical, saving weight (making road transportation feasible).

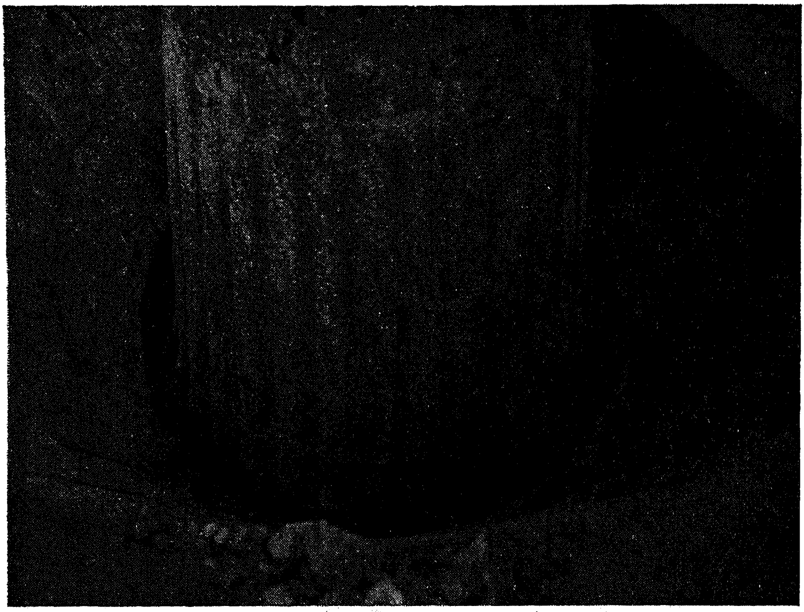


Fig. 1434. Gyratory crusher. When worn, the rotating member, known as a bell, is removed and hard-faced with high manganese steel electrode.

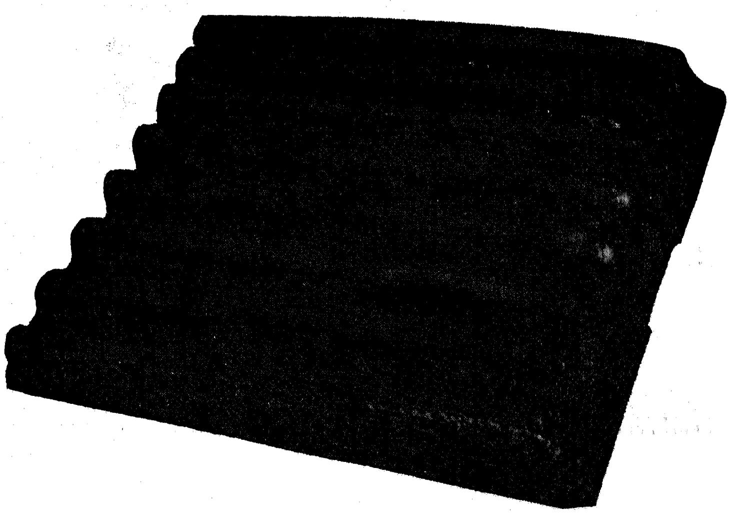


Fig. 1435. Intermediate stage in the repair of a worn rock crusher plate. Worn off ribs are replaced with one-inch round manganese steel bars as shown. These are then built up to the desired contour to provide the proper rib height. Welded with high manganese steel electrode.

Fig. 1436. Worn wagon track shoes built up with high carbon steel electrode last longer than when new.

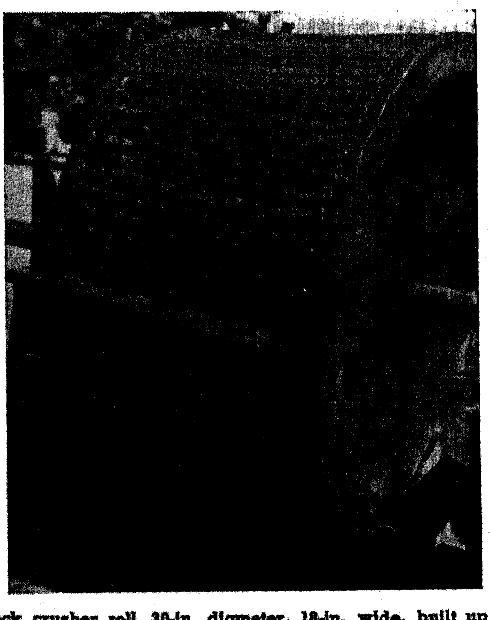


Fig. 1437. Rock crusher roll, 30-in. diameter, 18-in. wide, built up with 200 lbs. of high manganese steel electrode. Beads one-inch wide were laid and peened while cooling. Saved $85 over replacement cost.

Sheet Metal Work

Hundreds of sheet metal items such as fittings and ducts for heating and ventilating systems, store fixtures, architectural trim, containers, ventilators, machine guards, canopies, hoods, etc., are fabricated by electric arc welding for greater rigidity, strength, leak-proof joints, pleasing appearance and minimum cost. This work includes black iron, galvanized steel, aluminum, stainless steel, monel metal and other alloys as thin as 22-gauge. For procedure information see Pages 179 to 190. The following illustrations show typical applications. Others are included in other sections of this chapter.

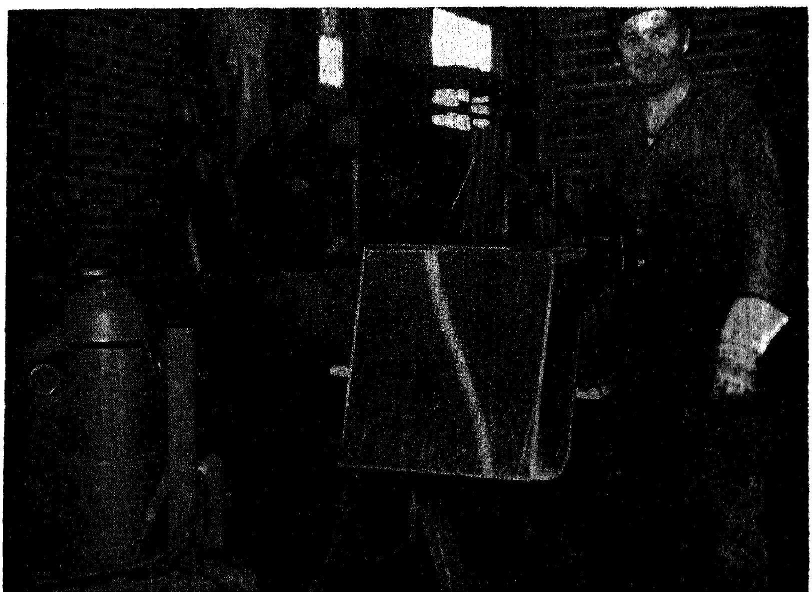


Fig. 1438. In this shop arc welding produces scale panel of 16-gauge stainless steel at a saving of 25% over other processes. The welds are free from pores and take a fine polish.

Fig. 1439. The smooth surface and round corners of this line of arc welded covers for steam radiators make them safe for school buildings, gymnasiums, etc.

Fig. 1440. Fabricating stainless steel edge band for a kitchen range. Built from three pieces of brake-formed sections welded at two corners into the U-shape part. Material is 20-gauge, 18-8 stainless steel. Copper inserts for backing up the weld are provided in a fixture.

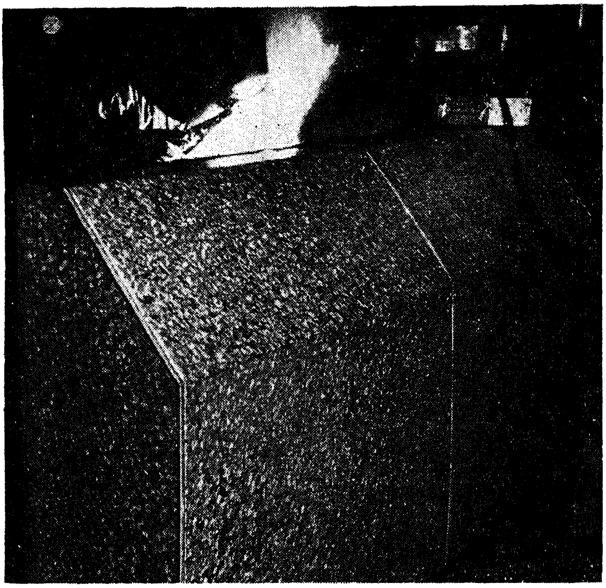


Fig. 1441. Fabricating a bakery oven unit from galvanized steel. This shop uses arc welding extensively for industrial heating equipment, baking and drying units, restaurant and kitchen equipment, show cases and ventilating piping.

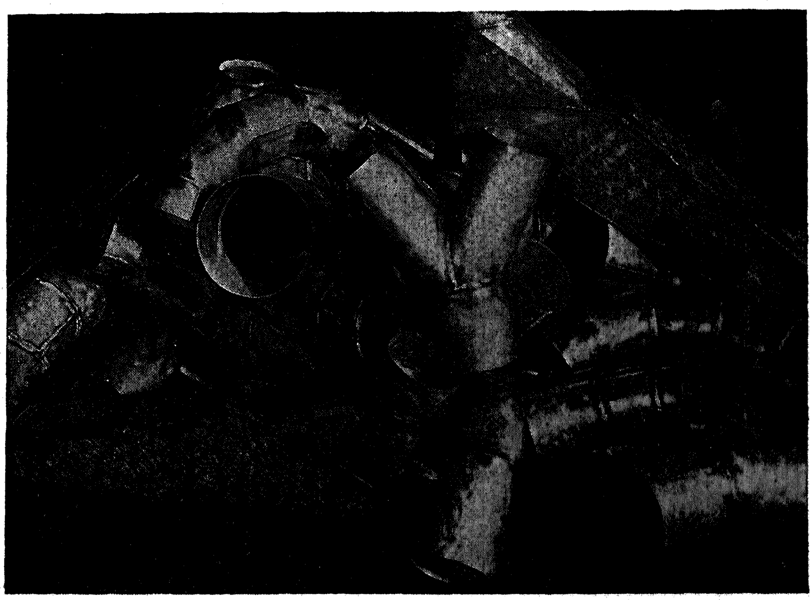


Fig. 1442. Elbows, Y's and other fittings for dust collecting systems fabricated from 22-gauge galvanized iron by the carbon arc process with copper alloy feeder rod. Joints are lap welds. Affords exceptionally strong, rigid, neat construction, replacing riveting and soldering.

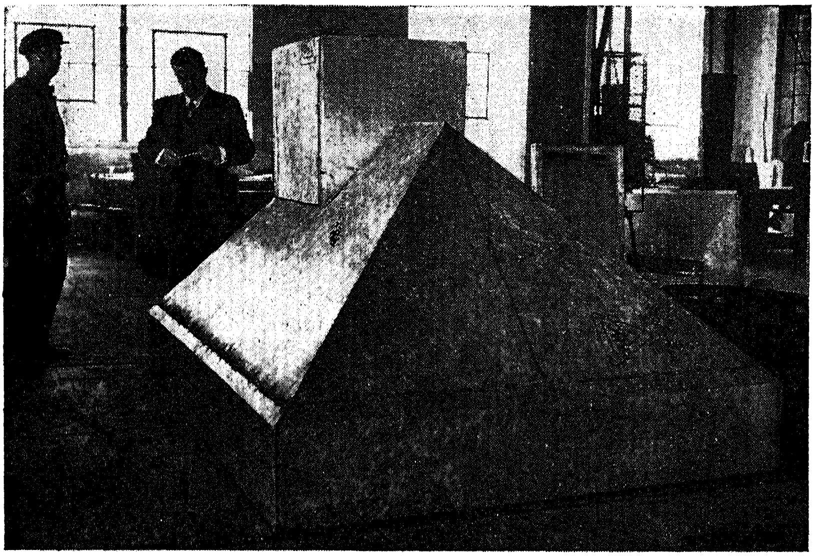


Fig. 1443. Hopper built from 20-gauge galvanized iron welded by carbon arc process with copper alloy feeder rod. Inside is reinforced by 1½-in. angle iron.

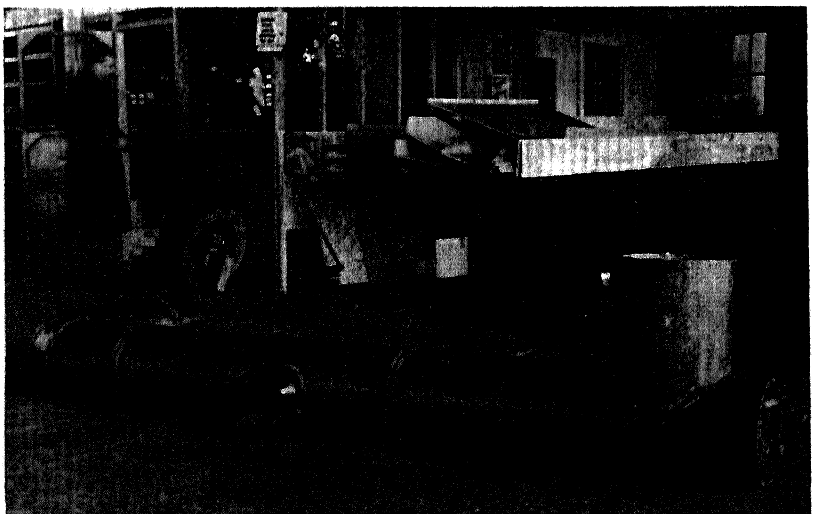


Fig. 1444. Smokestack duct fabricated from 16-gauge black iron welded with mild steel Type B shielded arc electrode.

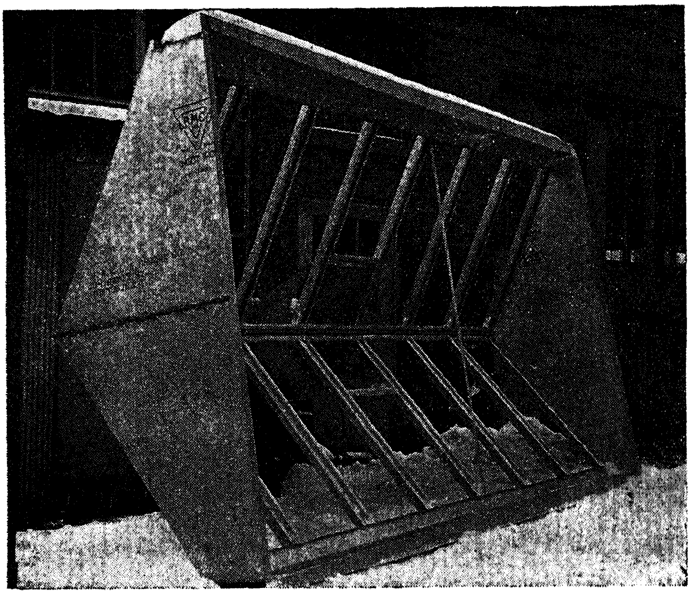


Fig. 1445. Skylight fabricated from galvanized iron by the carbon arc process with copper alloy filler rod. Size: 12 ft. by 9 ft.

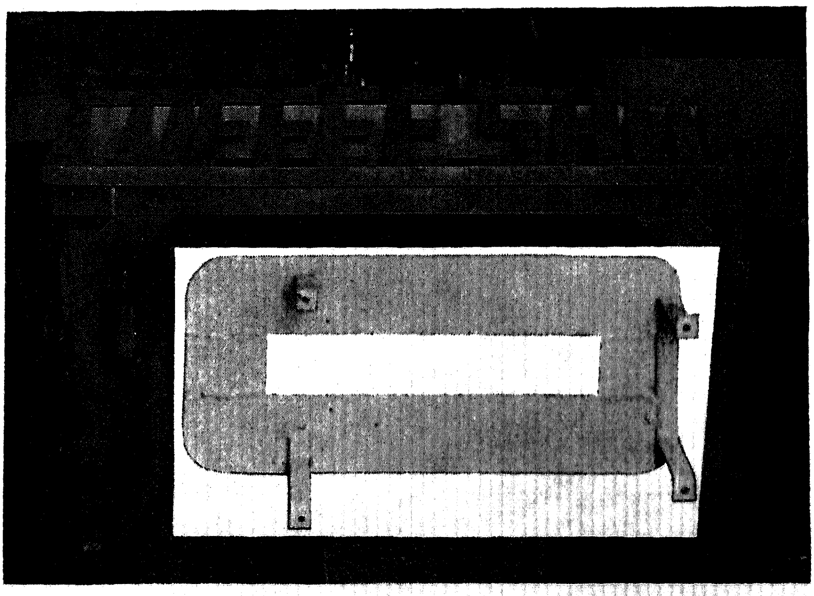


Fig. 1446. Letters sheared from 10-gauge strip, 2 inches wide, and fabricated by arc welding. For use on a neon sign with arc welded framework. Inset shows construction of letter and method of attachment.

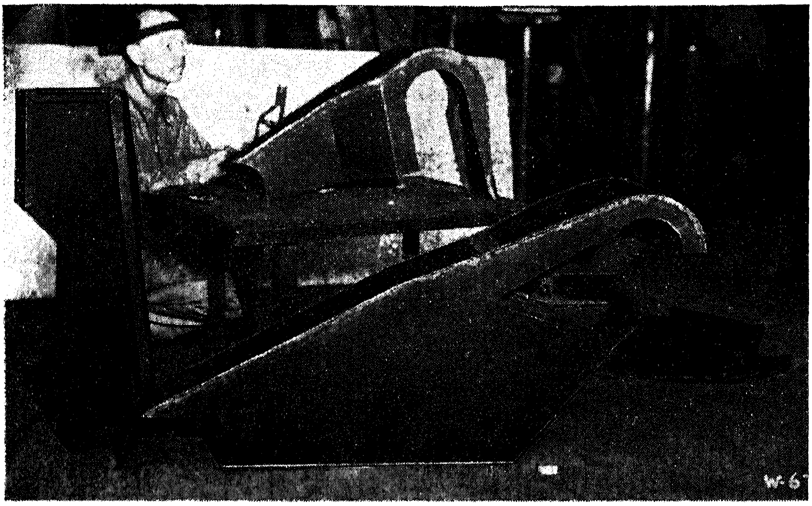


Fig. 1447. Machine guards built from black iron by shielded arc welding with Type B electrodes.

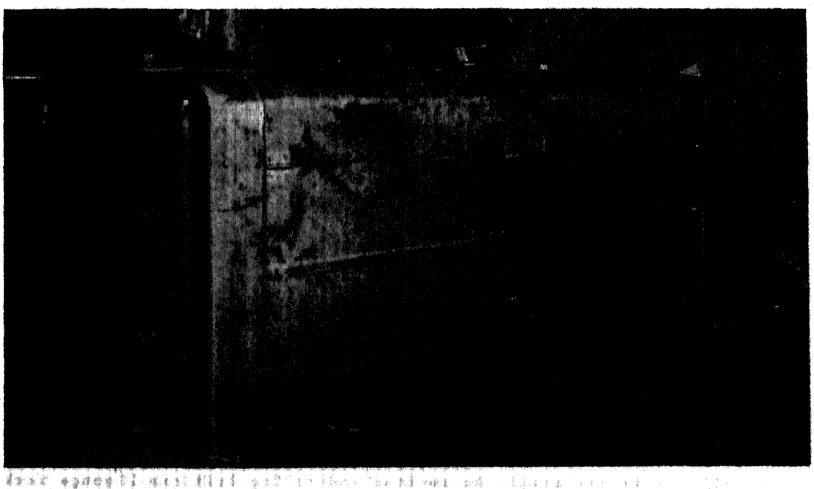


Fig. 1448. All welded canopy for a portable compressor fabricated from black iron.

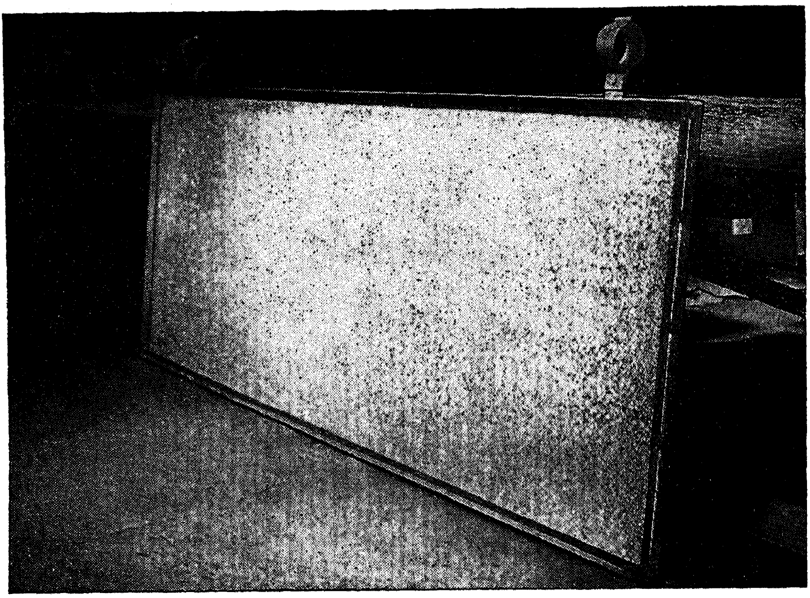


Fig. 1449. Sign frame of simple arc welded construction comprising a sheet of galvanized iron framed by one-inch angle iron welded all around on both sides.

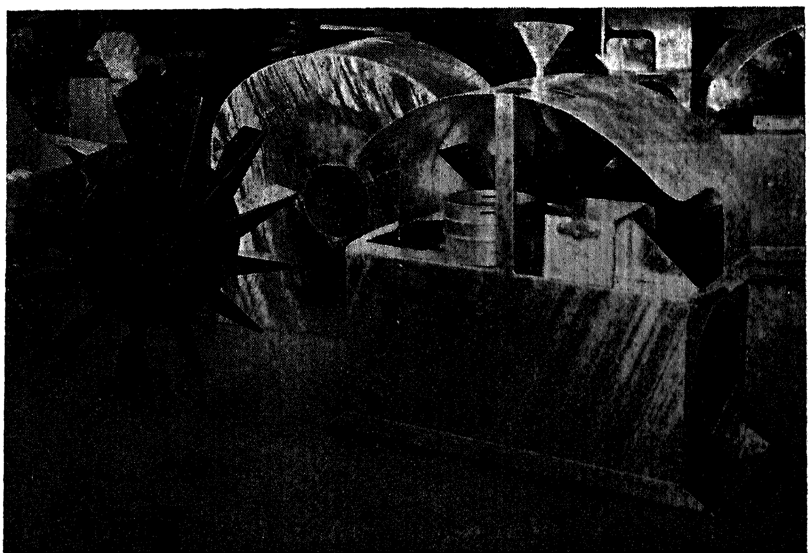


Fig. 1450. Special mud sampler for use in oil well drilling, built from 16-gauge black iron by arc welding. Galvanized after welding.

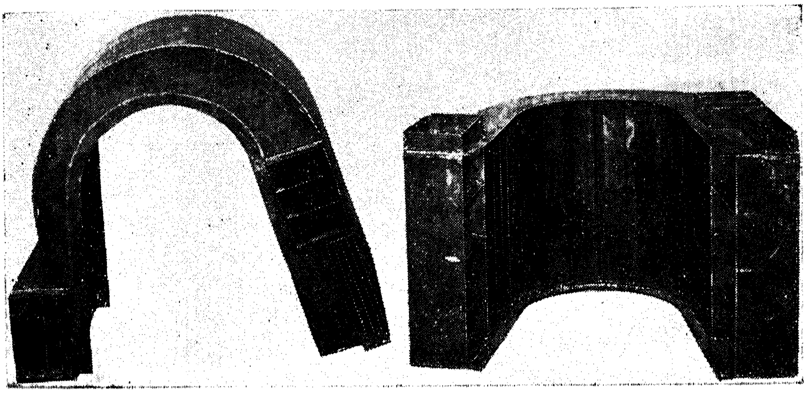


Fig. 1451. Intricate air ducts for special type of printing machine fabricated by arc welding from 18-gauge steel.

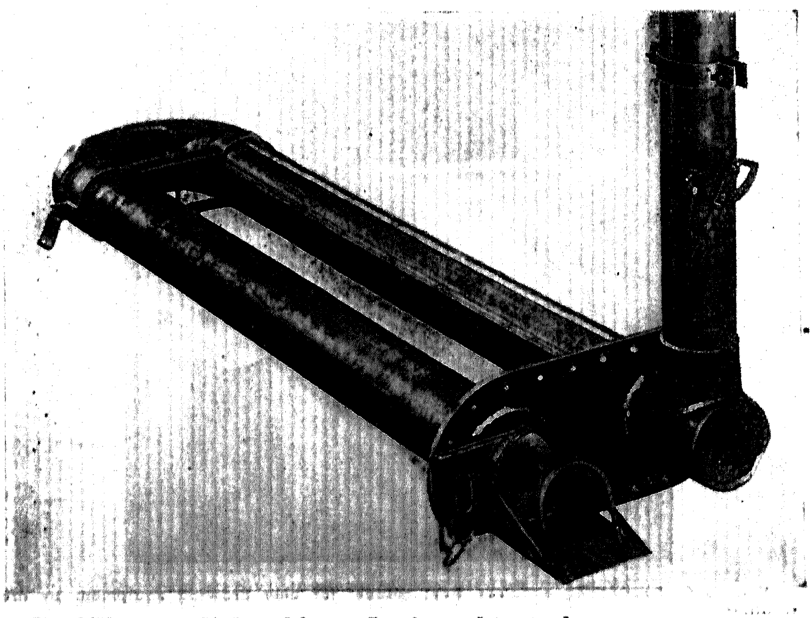


Fig. 1452. Arc welded steel heater flue for road tar truck.

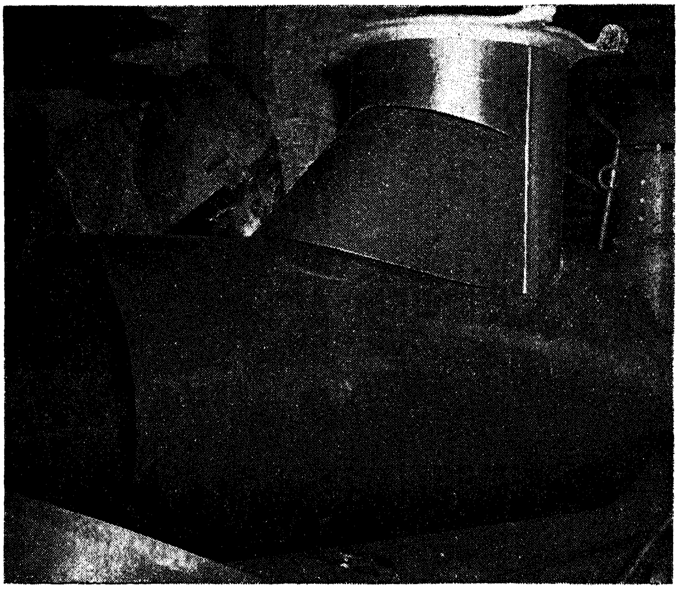


Fig. 1453. Fabricating aluminum laundry chutes by arc welding. This shop also arc welds a large number of stainless steel kettles for a process plant.

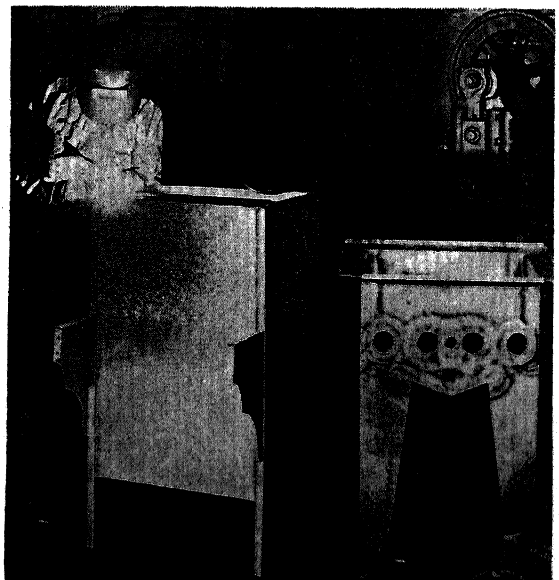


Fig. 1454. Fabricating stainless steel cabinet for beer drawing equipment by arc welding.

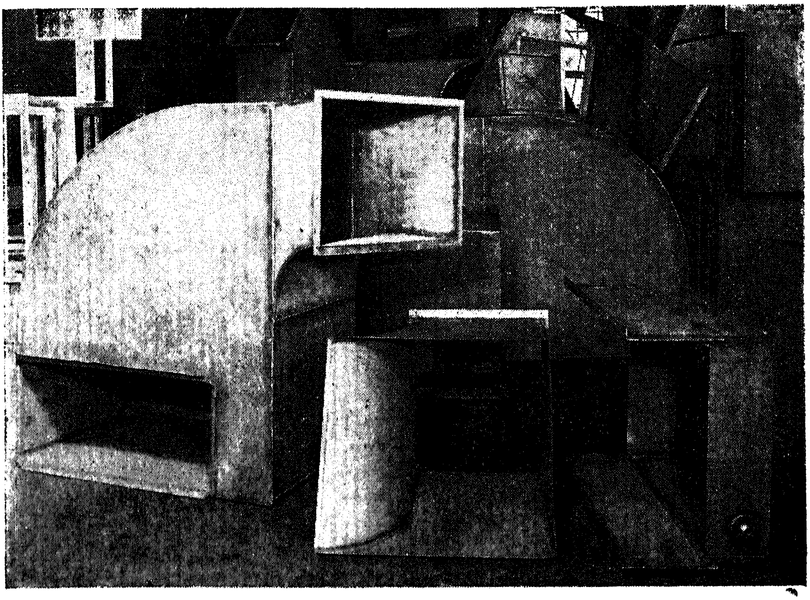


Fig. 1455. A group of air duct connections welded with the carbon arc with tinned copper alloy feeder rod.

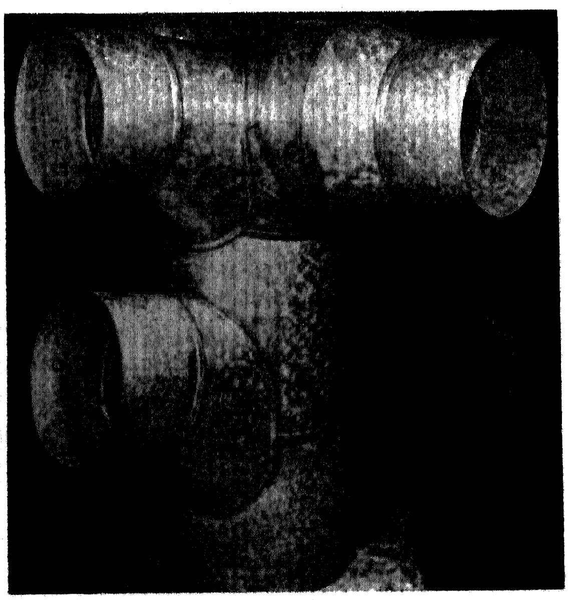


Fig. 1456. Special offset elbows for air ducts built from galvanized iron, welded by carbon arc with tinned copper alloy feeder rod.

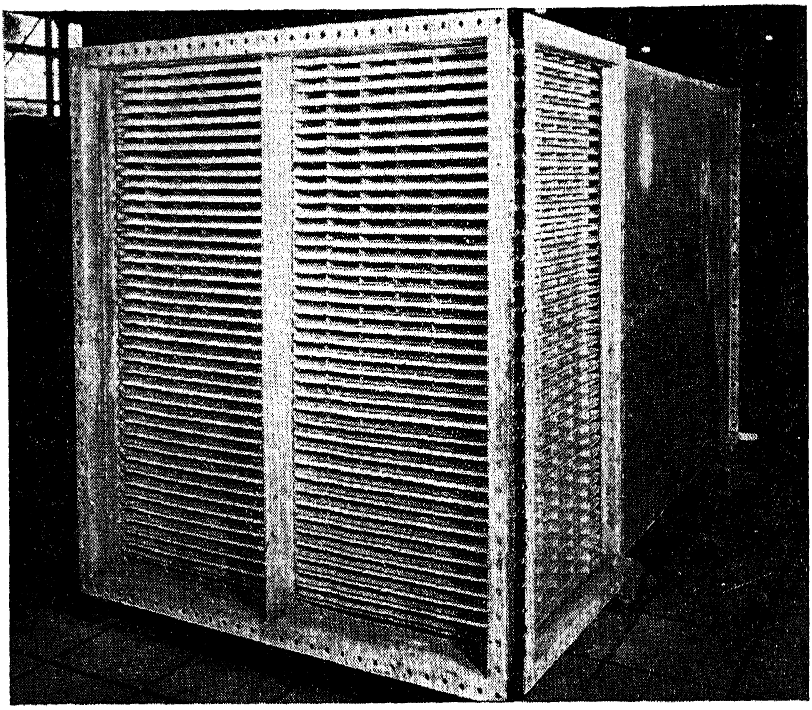


Fig. 1457. An interchanger weighing 8 tons constructed entirely from galvanized sheets (as thin as 24-gauge), plates and angle iron fabricated entirely by the carbon arc process with tinned copper alloy electrode.

Steel Mill Equipment

Electric arc welding has enabled manufacturers of steel mill machinery and the steel mills themselves to use their own product, rolled steel, in the construction of many pieces of equipment for greater economies in manufacture and maintenance. There are literally thousands of applications for arc welding in the fabrication of equipment and in the repair and reclamation of worn parts of steel mill machinery. A few typical applications are illustrated on the following pages.

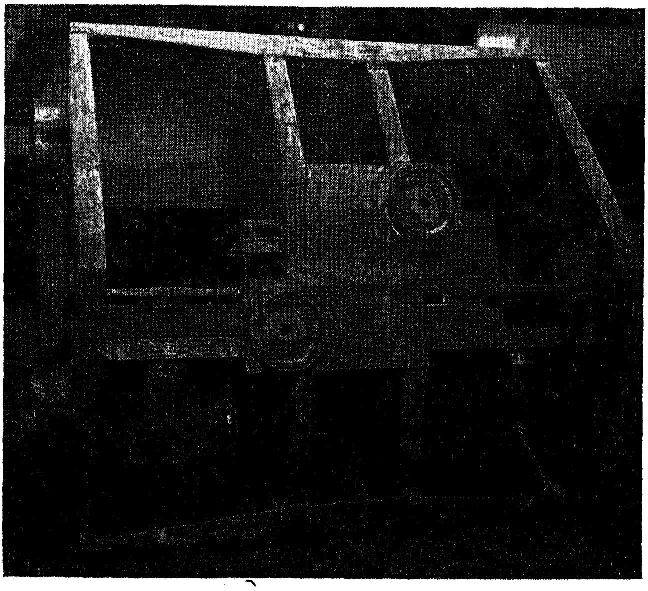


Fig. 1458. Arc welded head for a 24-ft. cleanup bucket fabricated from high tensile steel.

Fig. 1459. A blast furnace skip hoist with arc welded bed, gear reducer, brake beams, counterweights and other details.

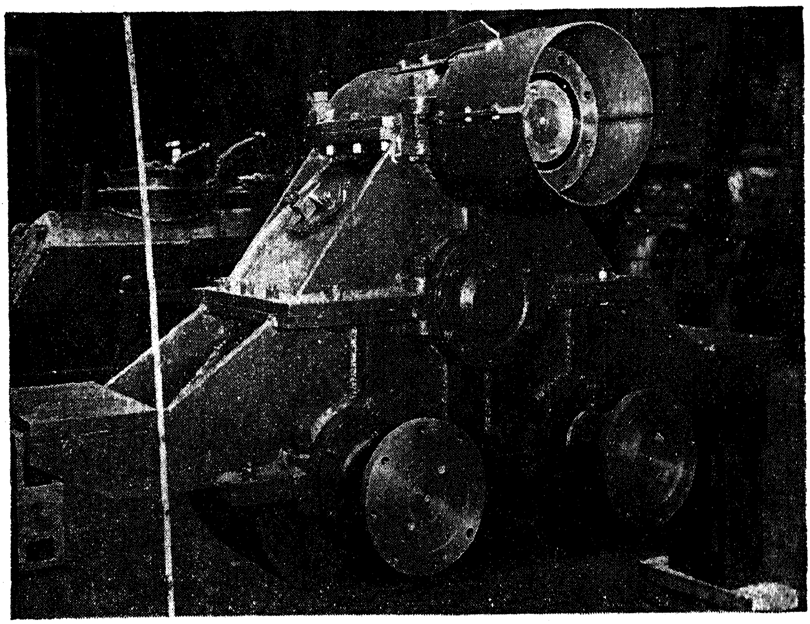


Fig. 1460. An arc welded propelling drive unit for an ore bridge.

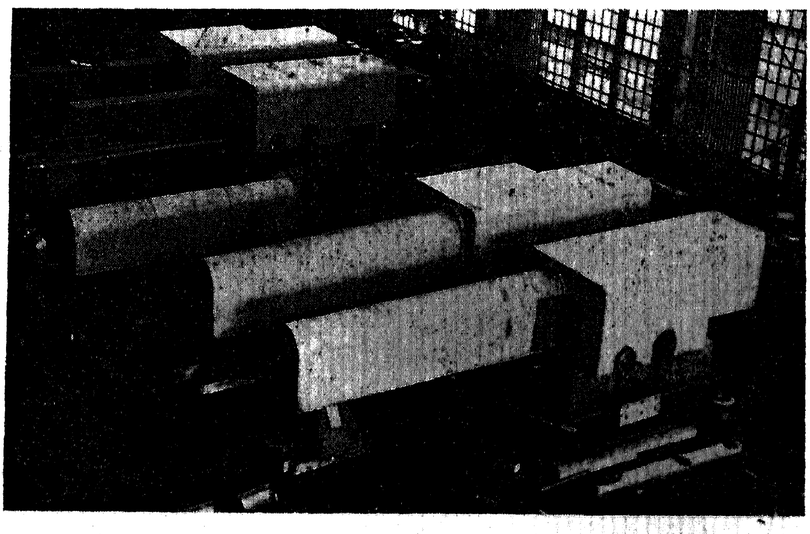


Fig. 1461. Arc welded gear reduction cases for self-sealing coke oven doors.

Fig. 1462. Complete arc welded transfer table.

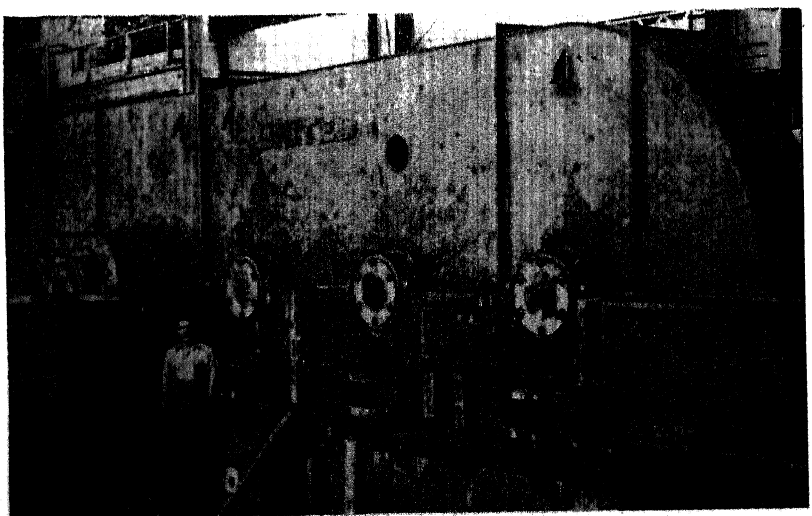


Fig. 1463. Bedplate and housing of this mill drive are completely arc welded.

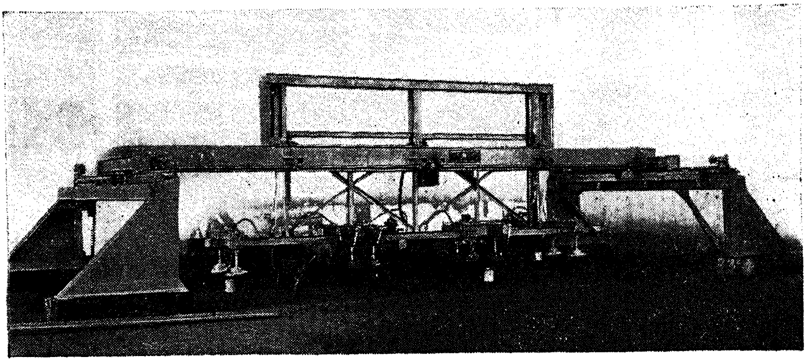


Fig. 1464. A sheet unpiler of arc welded steel construction.

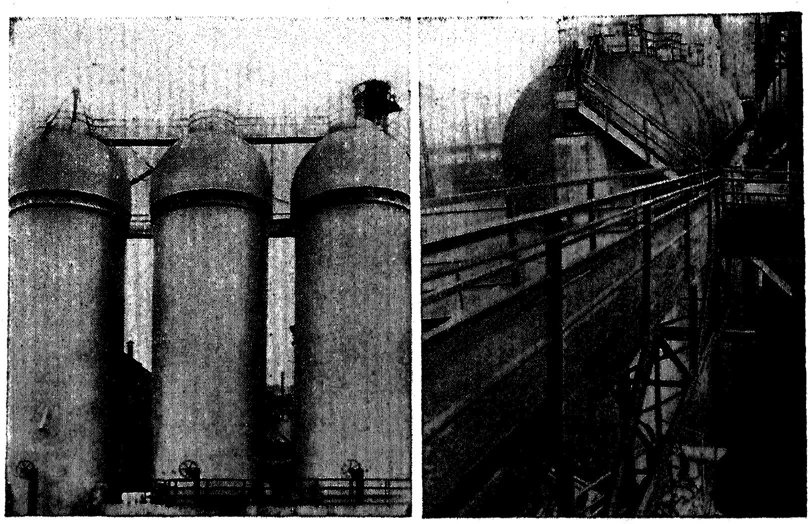


Fig. 1465. Six blast furnace stoves of all arc welded construction erected at a large Penn. steel mill. 24 ft. diameter, 104 ft. high, built from ¾-in. and ⅝-in. steel plates, butt welded. Saved 30% in weight and 50% in time of erection over conventional construction.

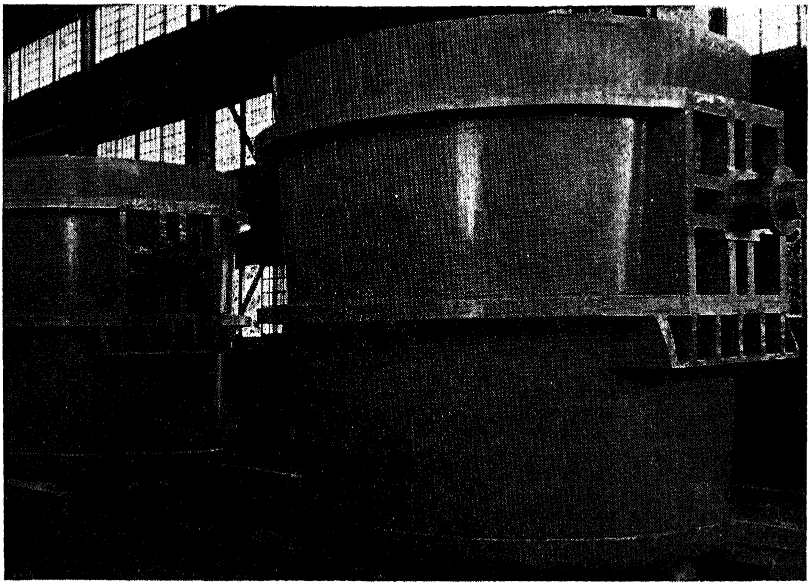


Fig. 1466. All welded open hearth ladles provide many improvements in design for longer life of linings and increased pay-loads. Capacity 140 net tons. Weight 39,250 lbs. without lining.

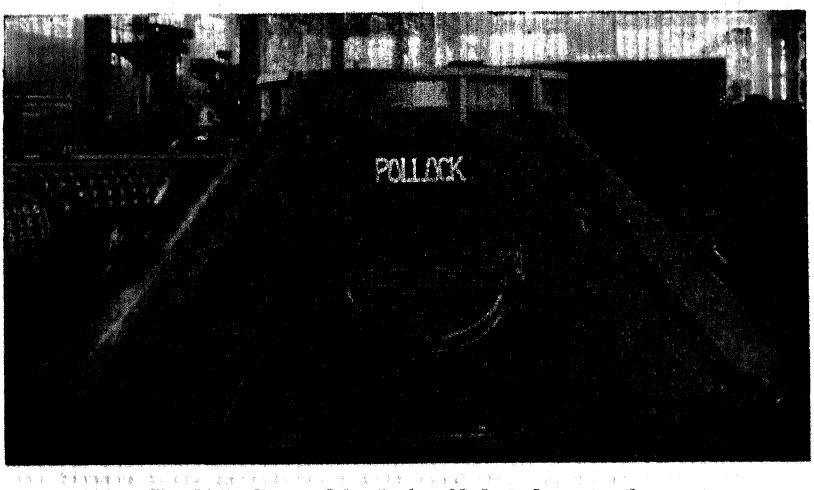


Fig. 1467. Gas seal hood of welded steel construction.

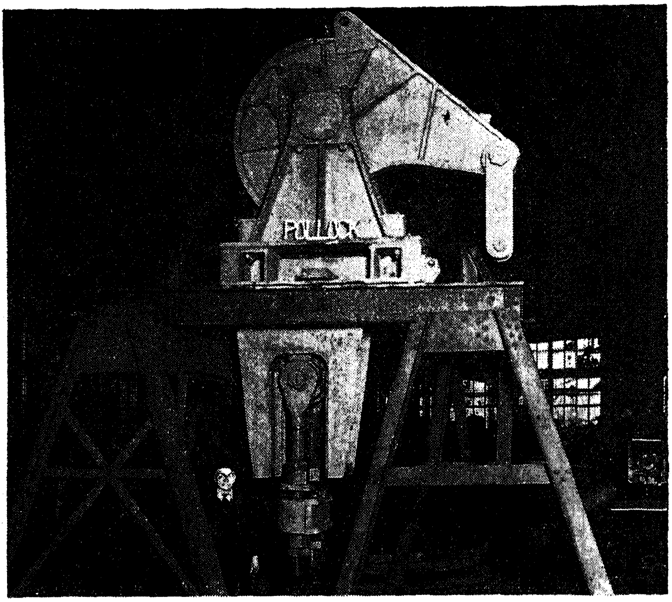


Fig. 1468. Welded steel provides a superior bell operating rigging. Note the interesting use of flange stiffeners.

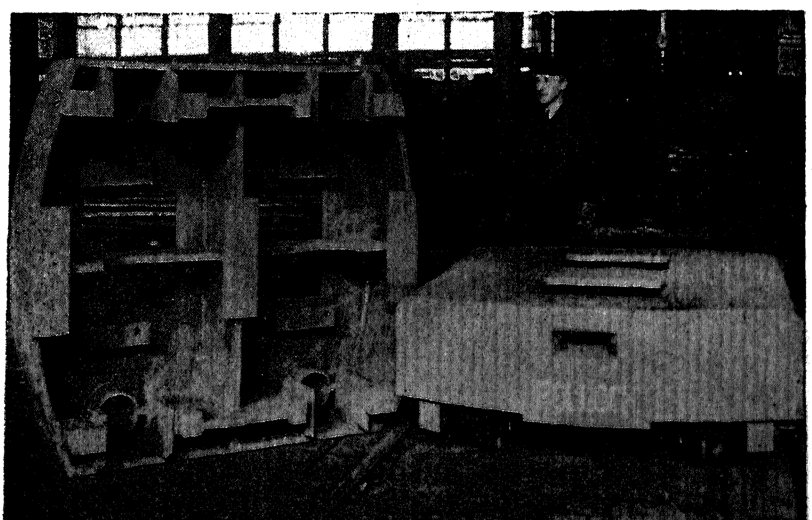


Fig. 1469. Ingot mould car. Left: Inside view of car showing use of standard steel shapes and plate to provide a low-cost, light-weight, rigid construction.

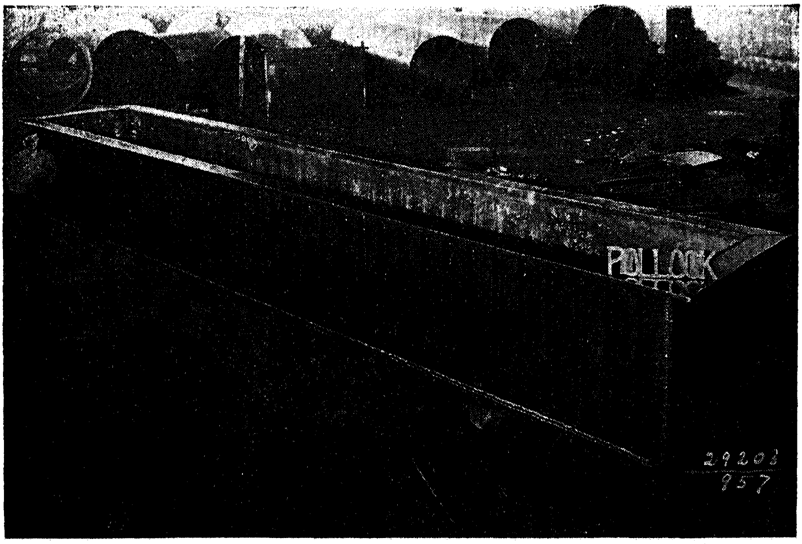


Fig. 1470. Galvanizing kettle made from heavy plates by arc welding. 48 in. wide, 48 in. deep, and 28 ft. 0 in. long.

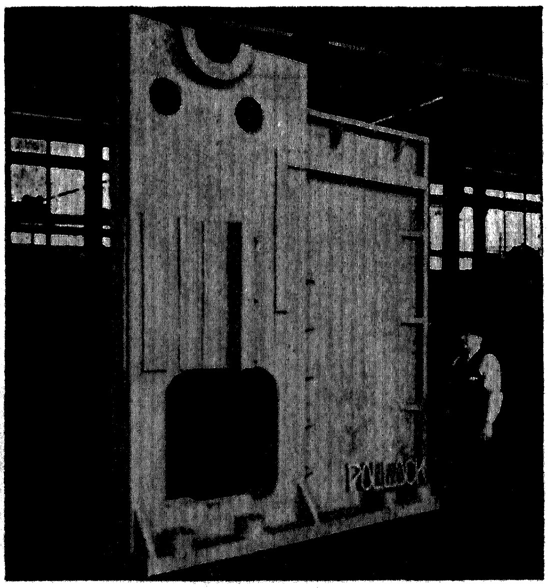


Fig. 1471. An interesting example of heavy plate fabrication. A tie plate and housing for a steel mill welded from exceptionally heavy steel slabs.

Fig. 1472. Blast furnace side jackets fabricated by arc welding.

Fig. 1473. A group of ladle stands fabricated from heavy flame-cut steel plate by arc welding.

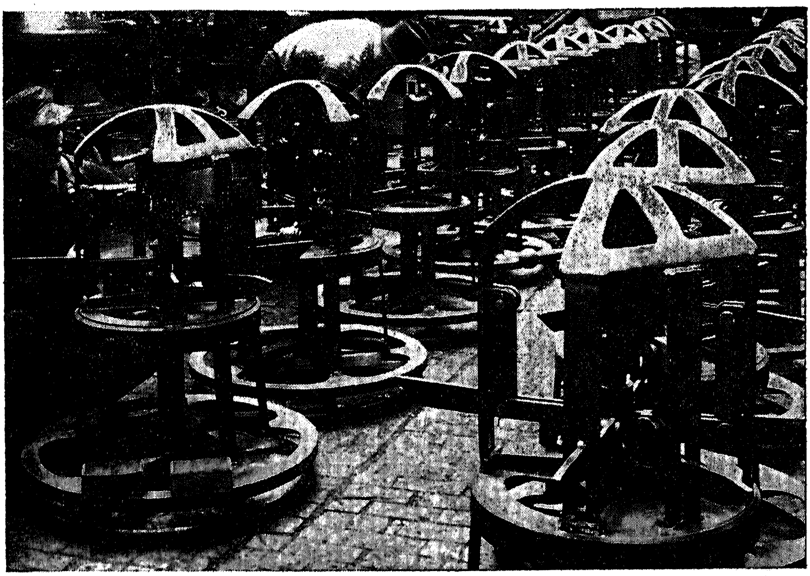


Fig. 1474. Wire reels of composite construction, employing both cast steel and welded steel parts.

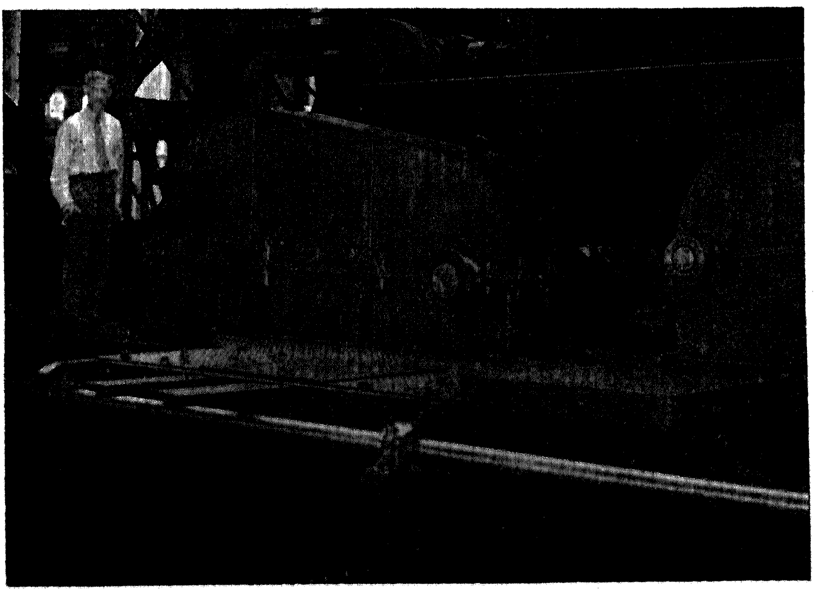


Fig. 1475. Coke pusher fabricated by arc welding for a large steel mill. The welded gear reduction cases for the ram and lever bar were built at considerable savings over the usual steel castings although the patterns were available.

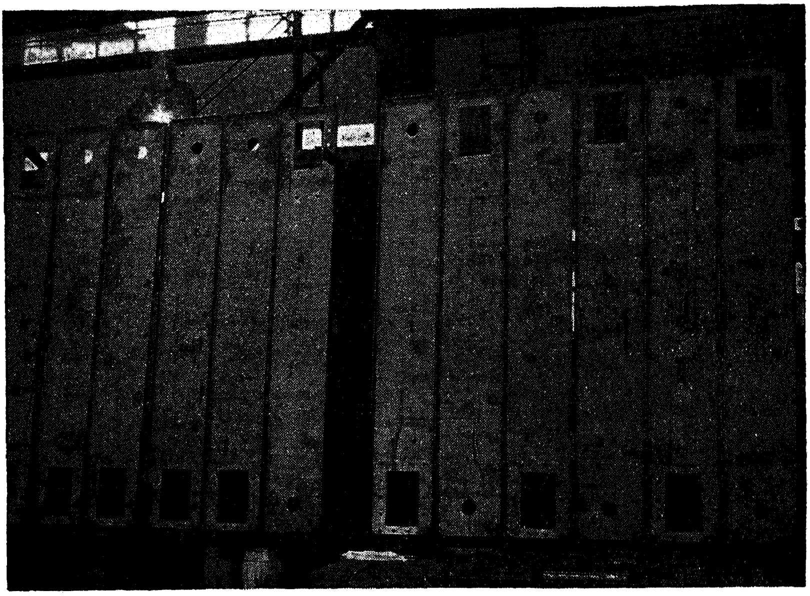


Fig. 1476. Arc welded coke oven door sealing plates built from ¼-inch plate 12 ft. long.

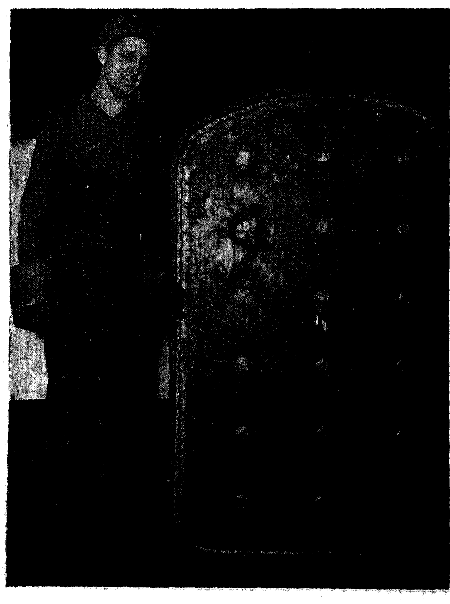


Fig. 1477. Gas valve used between gas producer and open hearth furnace of welded steel construction. Saved 1800 lbs. weight over cast construction formerly used, and eliminates breakage.

Fig. 1478. Water-cooled door for discharge end of steel mill slab re-heating furnace. Welded steel saves 1000 lbs. over cast construction. Cooling pipes are built in.

Fig. 1479. Repairing a broken scale-breaker pusher head. Six welders deposited 400 lbs. of mild steel shielded arc electrode and put the head back in service within eight hours, forestalling an expensive shut-down of the mill.

Fig. 1480. Building up worn face and inside seal of a floating ring for a hydraulic pump adding approximately ¼-in. of metal with ¼-in. medium carbon alloy steel electrode.

Fig. 1481. Fabricating an uncoiler coil box housing from flame cut plate and round bar stock. Majority of welds are two passes made with ¼-in. and 3/16-in. shielded arc electrode. Majority of plate is ¼-in. mild steel. Dimensions: 12 ft. x 5 ft. 9 in. x 3 ft. 4 in.

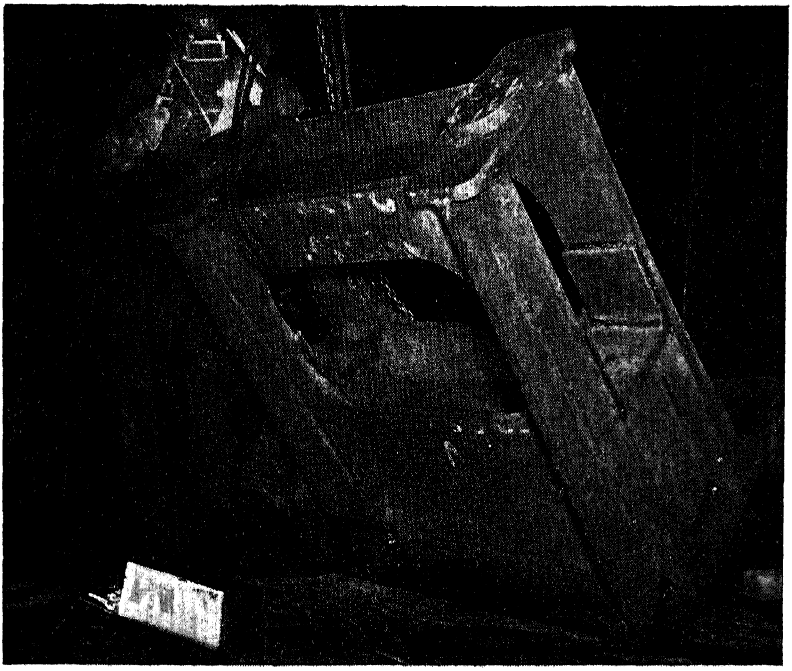


Fig. 1482. Fabricating a pinch roll housing built from flame cut $1\frac{1}{4}$-in. plate with mild steel shielded arc electrode.

Structural — Miscellaneous

In addition to its uses in the construction of buildings, bridges and tanks, discussed in other sections of this chapter, arc welding is used to advantage in the fabrication and erection of many other miscellaneous structures. Here, as in the case of bridge and building structures, this process assures maximum rigidity, strength and minimum weight. In many cases, too, it makes practical designs which greatly simplify construction and cut costs. A few typical projects are here illustrated.

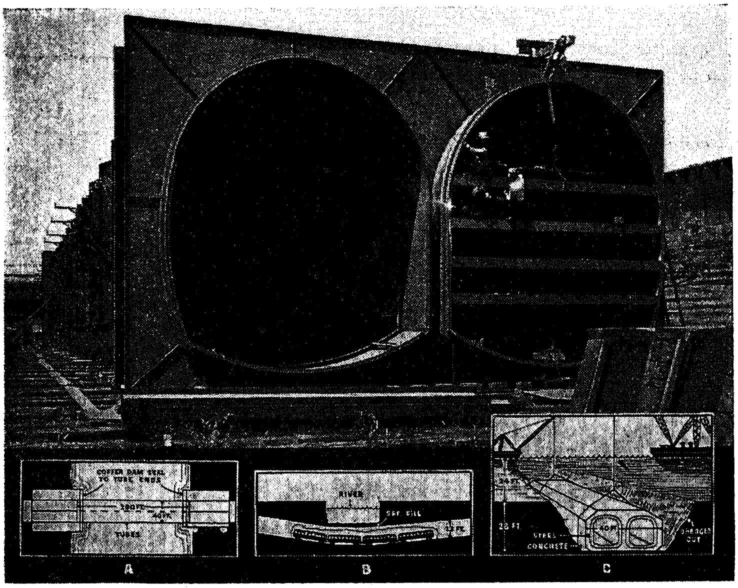


Fig. 1483. Twin type river tunnel for sub-way system. 200 ft. long, 40 ft. wide, 23 ft. high. Comprises 5/16-inch plate with T-bar stiffeners entirely arc welded. Pipe lined with concrete inside and outside with letters up to 3 ft. thick. Total weight of section 6500 tons. Towed from dry-dock 22 miles to installation site. Joined to cofferdam as shown in (A).

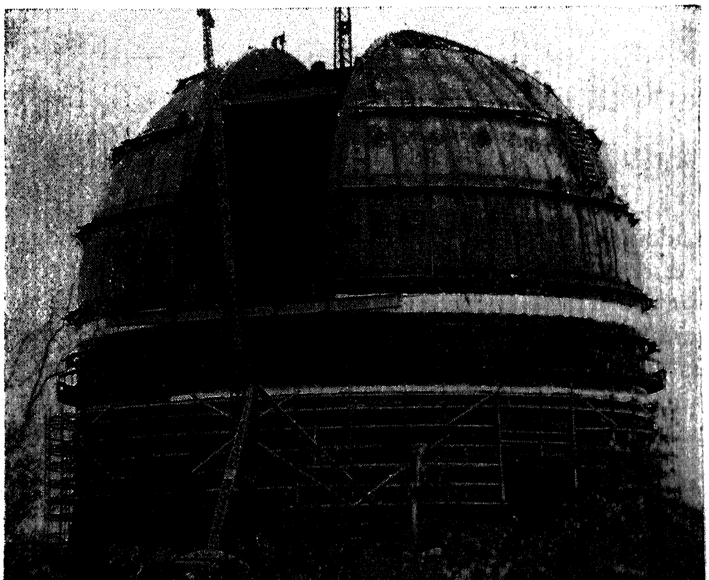


Fig. 1484. Dome for 200-inch telescope observatory of arc welded steel construction. Diameter 137 feet. Other arc welded parts of this world's record project include dome trucks which carry the 2,000,000 pound dome, shutter trucks which open and close the 130 ft. by 30 ft. opening in the dome, the dome drive, pedestals, vibration absorbers and much of the telescope itself.

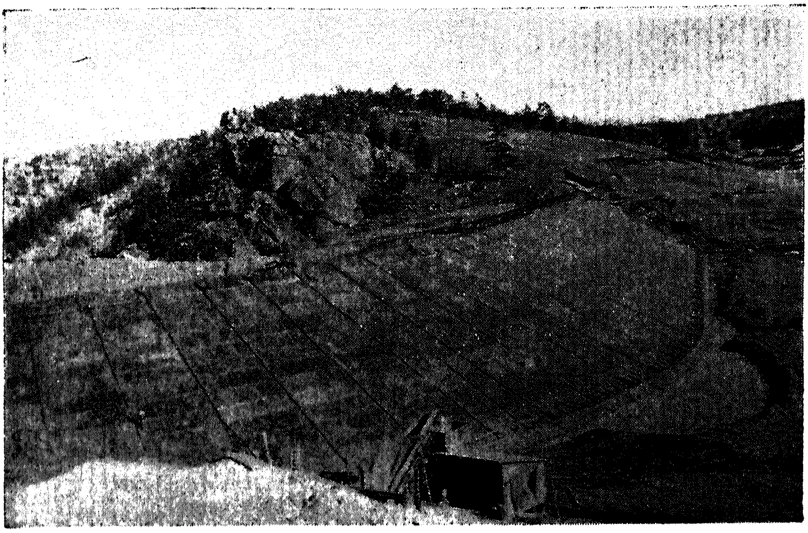


Fig. 1485. An earth dam, faced over its 150 ft. height and ¼ mile width with ¼-inch plate, welded from 8 ft. x 16 ft. and 8 ft. x 26 ft. sections. The reservoir stores 2500 acre feet of water.

Fig. 1486. Addition of second deck to ball-park pavilion at Cincinnati, Ohio, erected by means of welding. Includes 400 tons of steel. Increases seating capacity 3100. Inset shows how formed steel plate was welded into decks, runways and platforms.

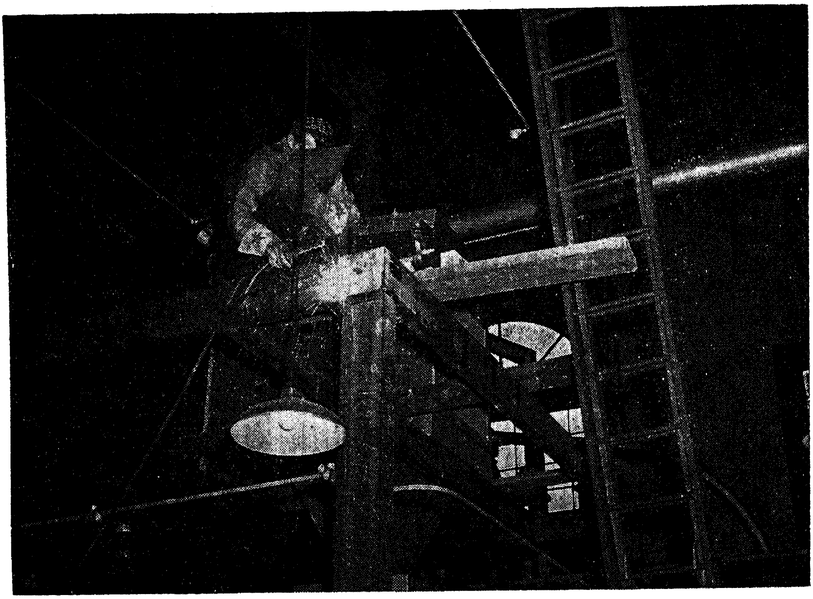


Fig. 1487. Erecting a structure for support of new grain mill in a brewery. Completely fabricated and erected by the welding department.

Tanks and Boilers

In the following discussion the term "tank" is used in a general sense to include all types except where specific types are mentioned. These types include all sizes and shapes of closed tanks, gas holders and pressure vessels, also open tanks such as vats, bins and hoppers.

Tanks may be classified according to size and duty. Size is determined solely by capacity requirements. Duty is determined by the operating conditions imposed. These two general classifications constitute the principal factors regulating the type of tank construction to be employed.

There are many sizes of tanks. For the purpose of this discussion they are placed in the following divisions:

(a) Small tanks, ranging in size up to 100 gallons. This division includes such tanks as pump tanks, barrels, domestic storage and small dispensing tanks.

(b) Medium tanks, ranging in size from 100 gallons to 3,000 gallons. Such tanks include storage tanks, septic tanks, vats, pickling tanks, etc.

(c) Large tanks, including bulk storage tanks, gas holders, and large storage bins and hoppers.

The various duties which a tank must fulfill may be determined by the following operating conditions which may occur:

(a) Pressure — which may be that imposed by content load or superimposed. Where high superimposed pressure is applied the tanks are generally known as pressure vessels.

(b) Temperature — must be considered when it is above normal especially when in combination with superimposed pressure.

(c) Chemical Reaction — This may be caused by tank contents or outside conditions.

To fulfill the duty imposed by operating conditions a tank must be permanently leakproof and have ample strength to carry all loads imposed.

In most cases, arc welded construction is used to fulfill these requirements for all sizes and types of tanks. It does this generally at a lower first cost and in practically every case at a lower final cost.

First cost includes material and fabrication costs. The first cost of arc-welded tanks is less because usually less material is required than for riveted construction. A riveted joint develops a maximum strength equal to only 80% of the strength of ordinary tank plate, but this is a very expensive joint to fabricate, whereas properly designed welded joints can be made by the shielded arc 20% to 30% stronger than the plate. Therefore the plate thickness or amount of material required for the design strength may be at least 20% less when the tank is built by arc welding. Another reason for the lower first cost of arc-welded tank construction is the elimination of practically all of the punching and all of the caulking required in building a riveted tank.

Final costs include first cost plus all maintenance costs and indirect costs, such as loss due to leakage, depreciation, etc. Maintenance costs of arc-welded tanks are practically negligible. The arc-welded joints are permanently tight. The weaving action prevalent in certain types of tanks does not affect tightness of arc-welded construction. Reference to the properties of weld metal, Page 282, shows that welds made by the shielded arc process have greater resistance to corrosion than mild rolled steel. Painting of exposed tanks is also easier where surfaces are smooth.

Construction of Small Tanks. — Small cylindrical tanks such as steel barrels or compressor tanks have longitudinal seams butt welded. The welding is generally done automatically for reasons of high speed production and economy. The ends of such tanks are usually flanged so that when inserted inside the shell an edge joint is formed. When a convex dished head is used the flange forms a butt joint with the shell. For examples of this type of container, see Page 784.

Small cylindrical tanks such as those used for domestic storage and similar purposes operate under no imposed pressure. This type of tank has lap welded seams in the shell. These may be welded manually or automatically. Where quantity of production is fairly large, automatic welding is most economical. The heads are usually flanged, inserted in the shell, and lap welded on the outside.

Small rectangular tanks such as service station oil dispensary tanks have a longitudinal seam at one corner. Such joints are generally corner welded on automatic machines. Heads and bottoms of these tanks are flanged, presenting edge joints for welding. Often an automatic pantograph mechanism is used to guide the welding head over the edge joints for welding. With such a mechanism pantograph templates are easily prepared for accurate guidance of the welding head over edge joints in practically any shape of tank.

Construction of Medium Size Tanks.—Cylindrical tanks of this type generally have lap-welded girth and longitudinal joints in the shell. The welding may be done manually or automatically. A typical automatic machine for welding such tanks is shown in Fig. 1490. This type of fixture can be built to accommodate practically all sizes of large cylindrical tanks that can be shop welded. The fixture can be raised or lowered to suit the diameter size of the tank to be welded. Where strength requirements necessitate double lap welds made on both sides of the joint, welds made inside the tank are done manually in all cases. The ends of the tanks are usually flanged and inserted within the shell, forming lap joints. Oval or odd shaped tanks such as used on trucks and trailers are usually welded by the manual process. However, in some shops special fixtures have been built for automatic welding of such tanks.

Rectangular tanks may be constructed in various ways, depending upon the size of tank, size of available plates and equipment available. Such tanks can be designed to have only transverse seams or only longitudinal seams or a combination of both. Approximately the same amount of plate will be used for any of these designs for a given tank.

The selection of the most economical design is therefore determined by the type of joints, and the amount of labor and welding required in the fabrication process. No definite rules can be made regarding the type of joint to use except possibly in the case where the tank requires buckstays or stiffeners. In such cases the plates can be butt welded together and to the stiffeners in one operation, the stiffeners acting as backing up strips for the butt welds.

Construction of Bulk Storage Tanks.—Prior to 1931, electric-arc welding was done with bare electrodes on field-erected tanks, but only on accessories, and nominally unstressed parts, such as cone roofs and flat bottoms. Now, however, there is no type of field-erected tanks, or parts thereof, which is not being satisfactorily welded in spite of the adverse conditions frequently encountered in the field.

Butt-welded girth joints are almost always made with string beads so laid that the finished weld looks as if it were formed by a number of parallel wires or strands nested in the groove.

Accompanying sketches show joint details typical of flat-bottomed storage tanks with vertical butt-welded cylindrical shells and dome or cone roofs; also joint details typical of the same structure with shells butt-welded where the plates are over 3/8-in. thick, and lap-welded where they are 3/8-in. and less in thickness. Both the vertical and girth

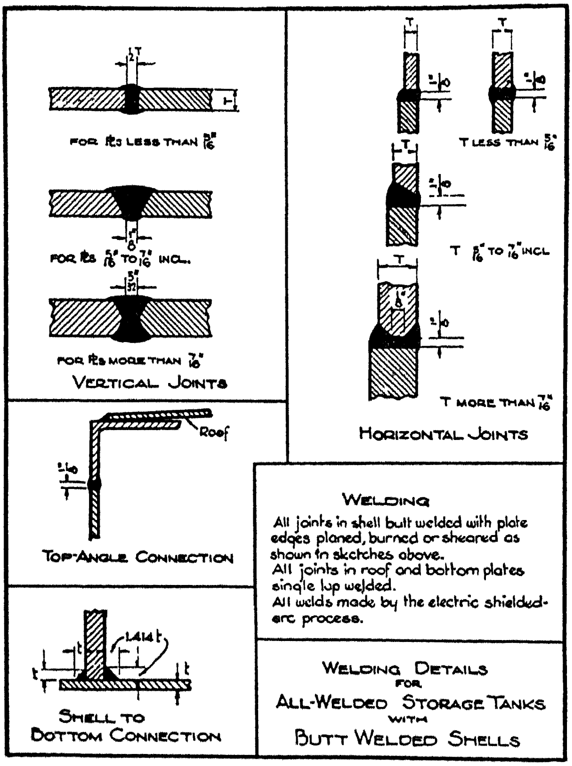


Fig. 1488. Details for tanks with butt welded shells.

joints are shown to indicate fusion throughout the entire plate thickness. Unquestionably the vertical joints, which are highly stressed, should be fully welded, but logically the girth joints, which are subjected to very small loads, need be welded only sufficiently to provide for corrosion, to hold the adjacent edges in line, and to provide a small reserve to withstand uneven settlement of the foundations. Nevertheless, because it is difficult to set up inspection standards for anything less, most companies are now providing, and many purchasers now requiring, complete fusion in girth as well as vertical joints. The lone exception is the direct shell-to-bottom connection, where a fillet bead is made each side of the shell.

In lap-welded construction, on the other hand, vertical joints are commonly fully welded on both edges only if the stress requires it, and girth joints are usually continuously welded on one edge and tack welded on the other.

Under the Tentative American Petroleum Institute Rules for Oil Storage Tanks, butt-welded joints are allowed an efficiency of 85%, fully welded lap joints an efficiency of 70%, and partially welded lap joints an efficiency of $50 + 1/5\ k$ %, where k is the percentage of full fillet intermittent welding on the partially welded edge. The minimum permissible value of k is 25%.

For welded oil storage tanks, the above joint efficiencies are applied to 21,000 lb. per sq. in., as a base for steels having a tensile strength of 55,000 lbs. per sq. in. or more.

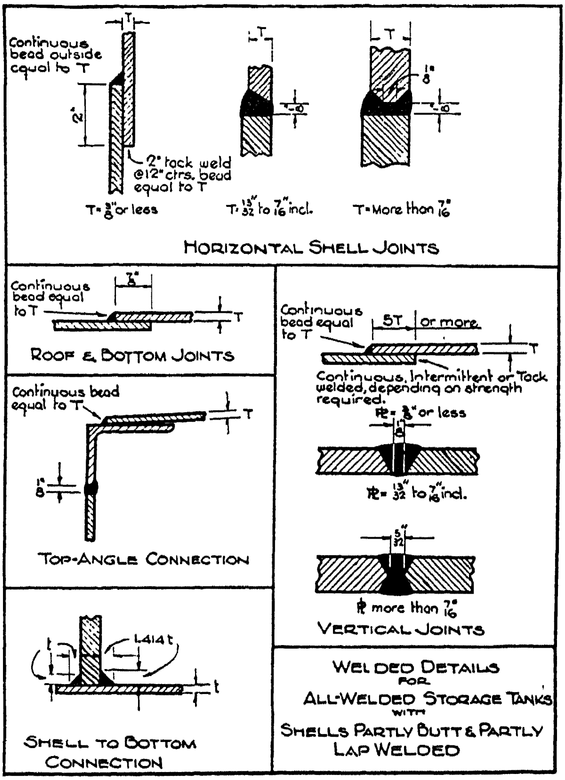


Fig. 1489. Details for tanks with butt and lap welded shells.

For such welded pressure tanks as spheres, spheroids, and cylindrical shells with hemispherical ends, the joint efficiencies are commonly applied to 13,750 lb. per sq. in, as a base for steels having a minimum tensile strength of 55,000 lb. per sq. in. Under the API-ASME Code governing the design of such vessels, the joint efficiency varies with the type of joint, the quality of material, and whether radiographing or furnace stress-relieving is employed. Under this code, the joints of a butt-welded vessel made of ASTM-A10 steel that are neither radiographed nor stress-relieved would be permitted an efficiency of only 74%. If ASTM-A70 firebox steel were used, other factors remaining the same, the efficiency would be 80%. If, in addition to using ASTM-A70 firebox material, the joints were radiographed, an efficiency of 90% would be granted, and if the vessel were both radiographed and stress-relieved, using A-70 firebox steel, the design could be based on joints having an efficiency of 95%.

Pressure vessels are almost invariably completely butt welded. For spheres and spheroids, a single-60°-V groove is commonly used. The upper half of a sphere is usually welded from the outside, against backing-up bars tack-welded on the inside to one of the abutting edges; the lower half is welded mostly from the inside, but a small groove is chipped from the outside, along the apex of the V, into good weld metal deposited from the inside, and then filled by overhead welding.

The bottoms of spheroids are commonly laid directly in the sand or earth bed prepared for them, and butt welded together from the top side against backing-up bars on the underside. The roof plates are similarly welded from the top side against backing-up strips. The side sheets may be welded from both sides—or from the outside only, against bars on the inside.

It is no longer considered advisable or necessary to drill or punch holes in plates for assembly purposes. Devices have been developed by which plates are quickly and accurately assembled, and the gap between abutting edges adjusted to and held at the desired amount.

To avoid unsightly buckles and dangerous cracks, it is necessary that pieces be welded in proper sequence and with as little restraint as possible to normal shrinkage. For example:

The vertical joints in each shell ring of an oil storage tank are fully welded before the ring is welded to the course above and below. The vertical joints of the lowest shell ring are completely welded, and the lower edge of the ring then welded to the outer bottom plates before the latter are welded to each other or to the interior bottom plates. The interior bottom plates are next welded into sections, then the sections welded together, and finally the outer bottom plates are welded to each other and to the interior plates. If the bottom were welded into a complete disk, and then the shell welded to it, cracks along the bottom edge of the shell would probably result, because the tendency of the shell to reduce in diameter as welding progressed would be resisted by the nearly rigid bottom.

Bins and hoppers may be regarded essentially as tanks, the only difference being the contents are solids instead of liquids or gases. These are either rectangular or circular in shape and generally have dispensing funnels.

Pressure vessels are primarily tanks of heavy construction which operate under medium or high pressure and also sometimes under high temperature. Many hundreds of pressure vessels have been built of arc-welded construction and their success in operation offers conclusive proof of the reliability of this method of construction. Pressure vessels should be built in accordance with the A.S.M.E. Boiler Code, which requires definite procedure of welding and stress relieving, and for certain types of pressure vessels stress relieving in furnaces. Butt joints are used entirely in this class of work. Plate thicknesses generally range from 1 to 3 inches. Practically all welding of pressure vessels is done by the shielded arc process, either manually or with a welding head which automatically feeds into the arc the metallic shielded arc electrodes. See Pages 157 to 162, also Page 246 for method of preparation of joints, welding procedure and speeds for this class of work.

Cost Factors of Arc Welded Tank Construction.— The requirements or service conditions to be met by the tank must be most thoroughly and carefully studied. The care with which this study is made determines very largely the costs which will result, both first and operating. The study must include the shop and the field.

First is the fabrication in the shop. The plates must be shaped. Rolls may be used either for hand or automatic jobs. The arrangement or sequence of shop operations has great effect on costs. After the plates have been cut and formed, the accuracy of their assembly aids in cost reduction when the plates have been delivered to the field and are erected.

Fit up may be considered from two viewpoints. First, the accuracy of cutting, forming, etc. Next the means of holding in place or assembling, while welding. The plates must be held in position while welding is being done. There are a number of methods for doing this. They consist essentially of clamps, either welded in place or movable so that welding may proceed at a satisfactory rate. A good tight fit up will naturally increase speeds and result in considerable saving in electrode.

Arc welded tanks and boilers of a variety of types and sizes are illustrated on the following pages.

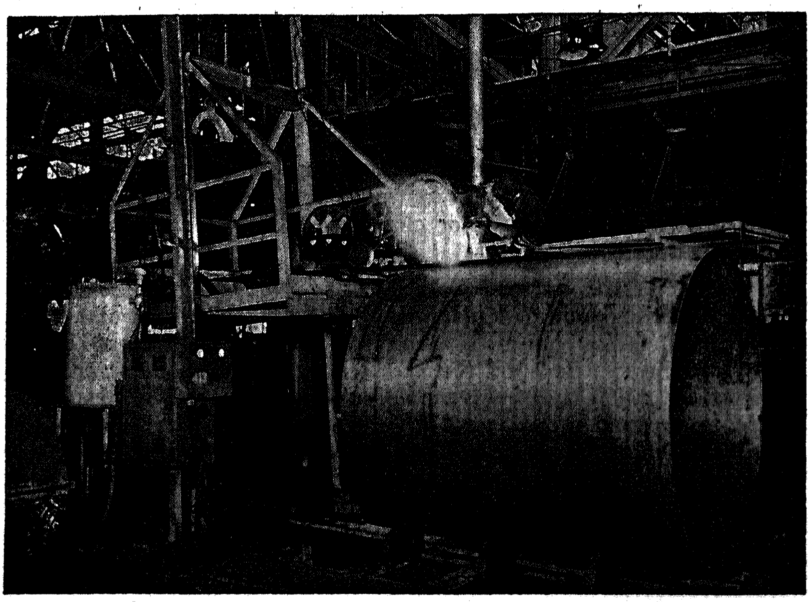


Fig. 1490. Shop fabrication of storage tanks with a tractor type automatic shielded carbon arc welder.

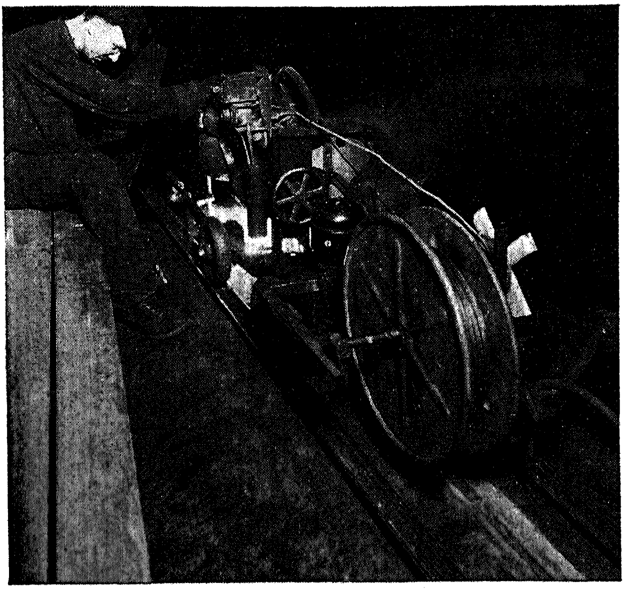


Fig. 1491. Close-up of welding operation in the construction of the tank shown in Fig. 1490. Tractor automatic welder travels in angle iron track as shown.

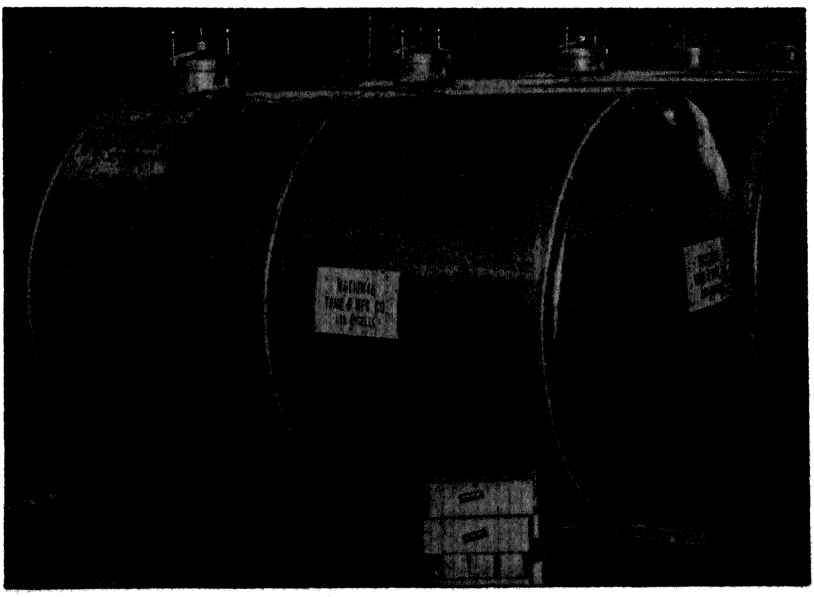


Fig. 1492. Aluminum tanks of arc welded construction used for storing olive oil.

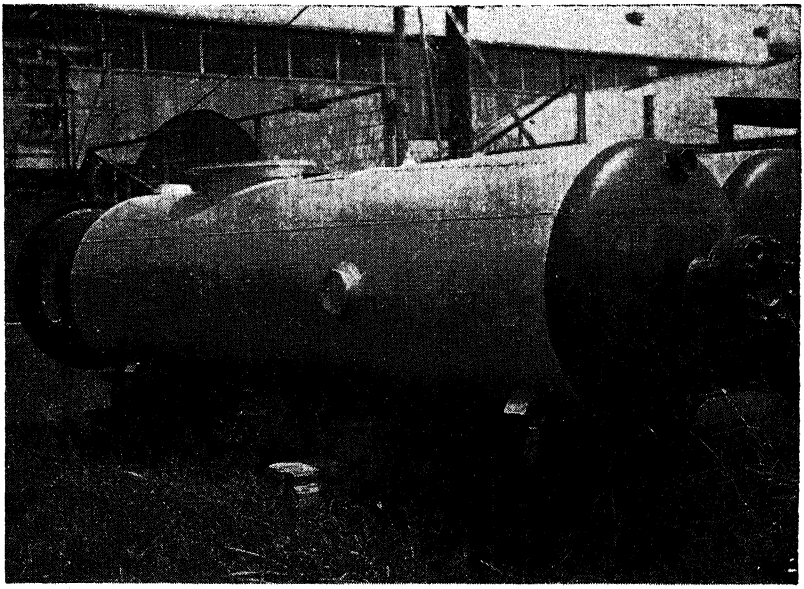


Fig. 1493. Oil and gas separator welded from high tensile steel. Size: 11 ft. long, 24 in. o.d., 1⅞-in. plate. Tested under 3500 lbs. pressure.

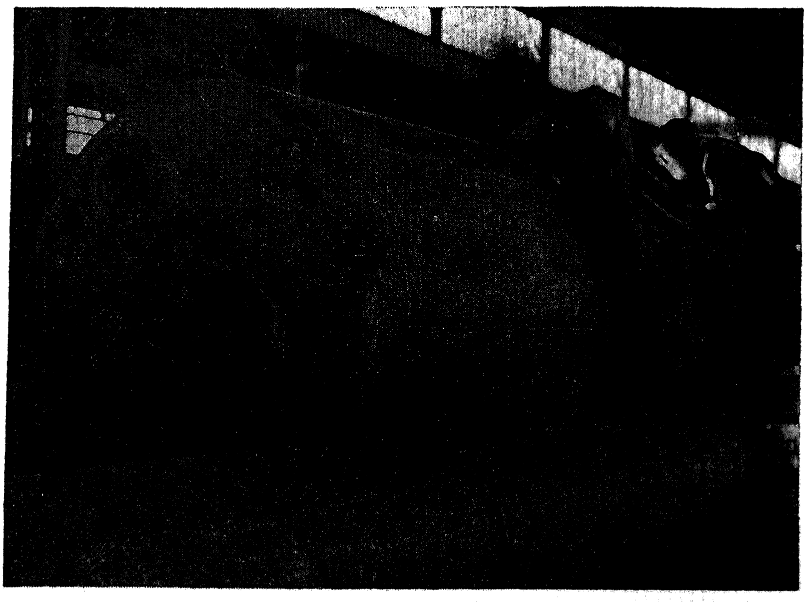


Fig. 1494. Fabricating an oil storage tank by shielded arc welding.

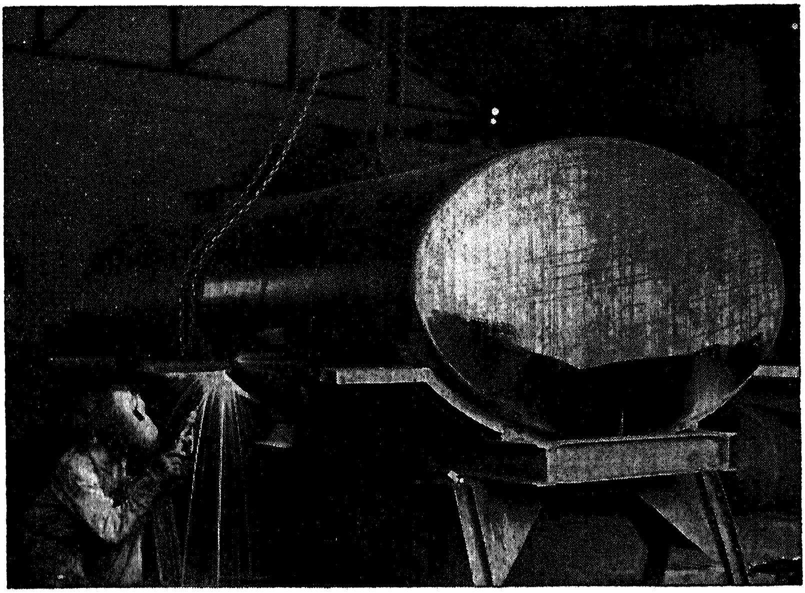


Fig. 1495. Building a truck tank for transportation of gasoline. Shielded arc welding is used almost exclusively for such equipment.

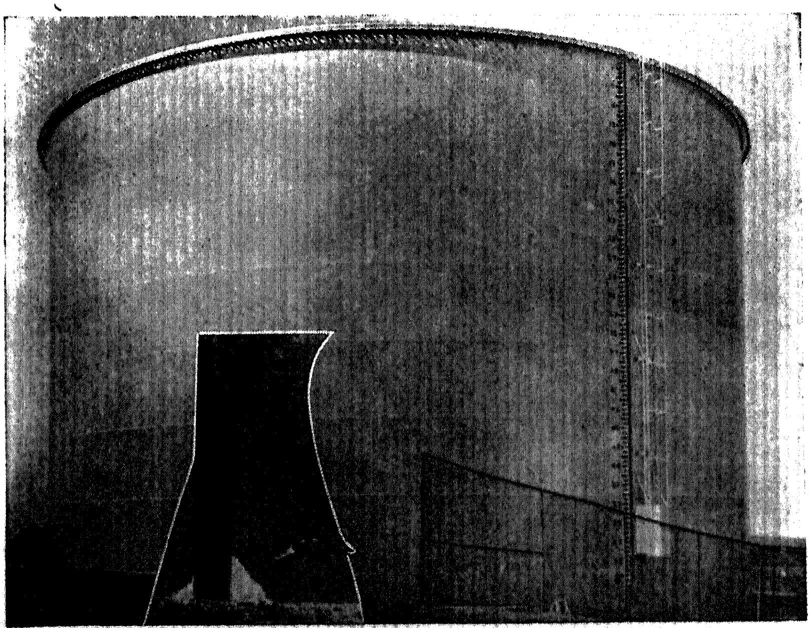


Fig. 1496. Construction of all-welded 2,000,000 gallon water storage tank. Comprises eleven rings butt welded with double J joint for horizontal seams and double V joint for vertical seams. First ring is 1-7/16-inch plate. Each successive ring is 1/8-inch smaller than one below. Inset shows close-up of 2-inch fillet welds joining 1-7/16-inch plate of first ring, and 3/16-inch base plate.

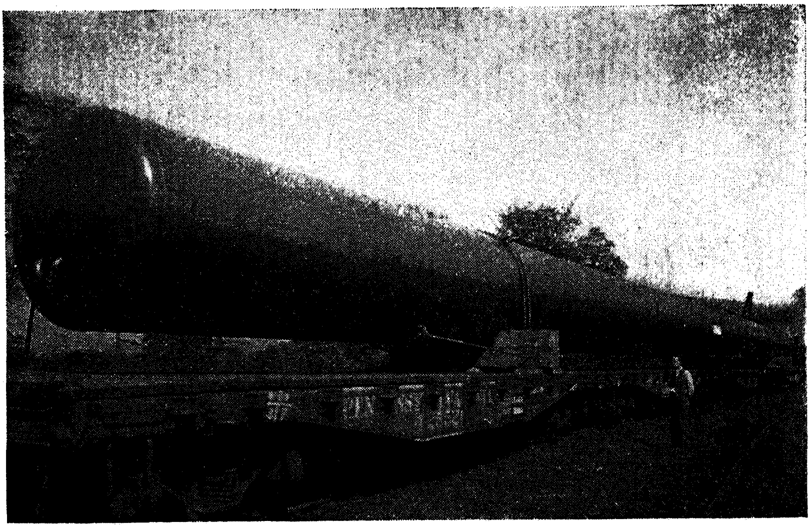


Fig. 1497. Pressure vessel for creosoting purposes. 160 ft. long x 6 ft. diameter. ⅝-inch shell. ⅞-in. head. Weight 110,000 lbs. Welded complete in 10 days by automatic shielded carbon arc process—A.S.M.E. U-69 code.

Fig. 1498. Treating tower for oil refinery. 65 ft. long x 8 ft. diameter. ⅝-in. shell. ¾-in. head. Includes 19 trays inside. Welded by automatic shielded carbon arc process—A.S.M.E. U-69 code. Fabricated, assembled and tested in 18 days.

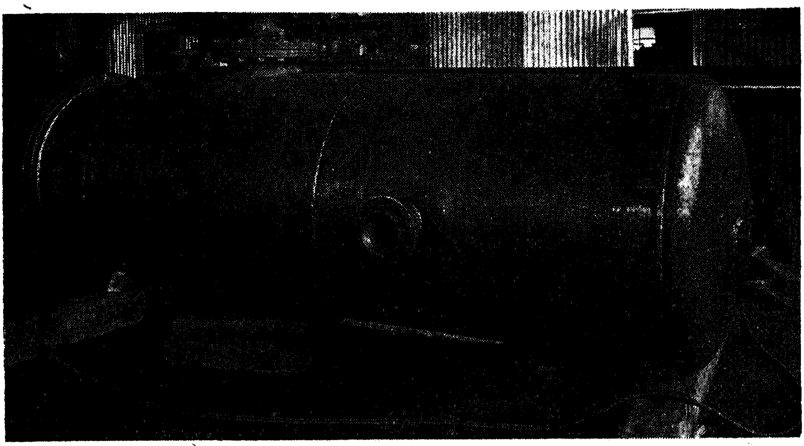


Fig. 1499. Pressure vessel arc welded according to A.P.I.—A.S.M.E. codes with Type C deep-groove electrodes. Shell thickness ⅝-in.

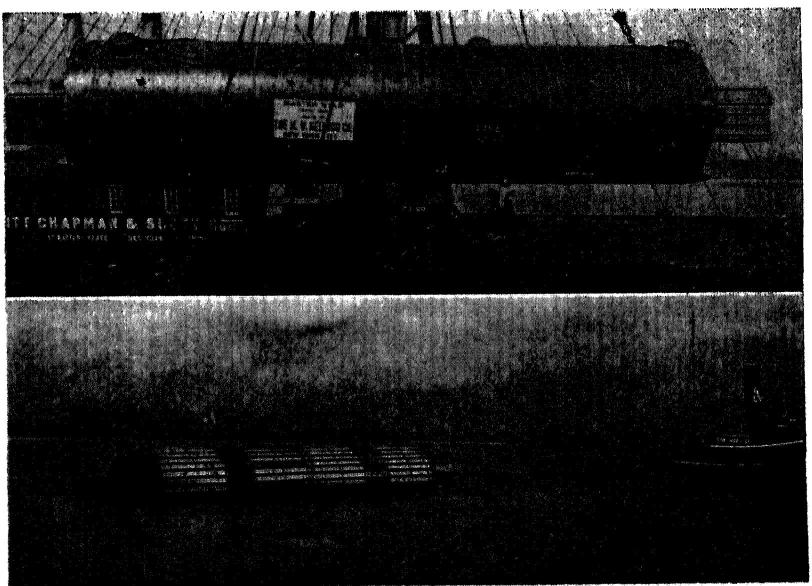


Fig. 1500. World's largest evaporator tower of all welded construction. 82 ft. 6 in. long, 15 ft. I.D., 2 5/16-in. thick. Weight 480,000 lbs. Towed 1400 miles by water to its destination as shown at bottom.

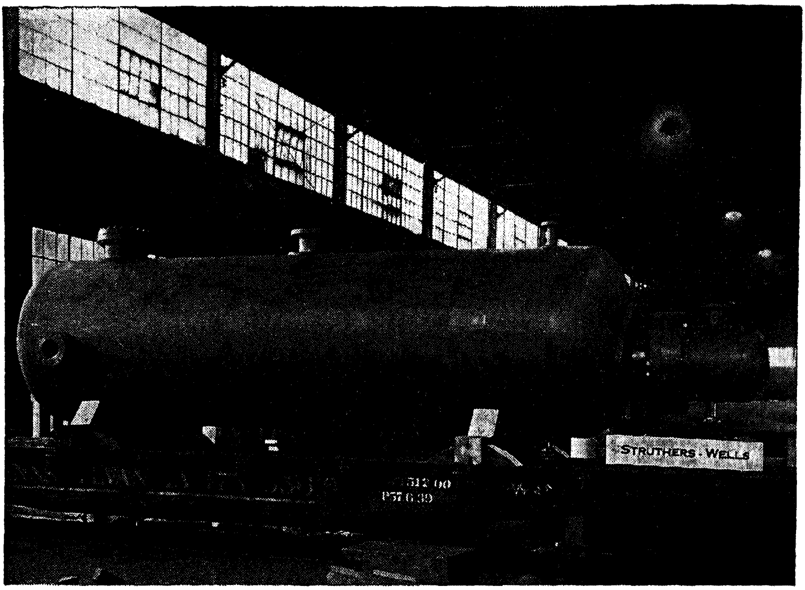


Fig. 1501. Shell and tube reboiler. 6 ft. x 20 ft. 1¼-in. plate. 400 lb. working pressure. Weight 40,000 lbs. Welded according to A.P.I.—A.S.M.E. code, stress relieved and X-rayed.

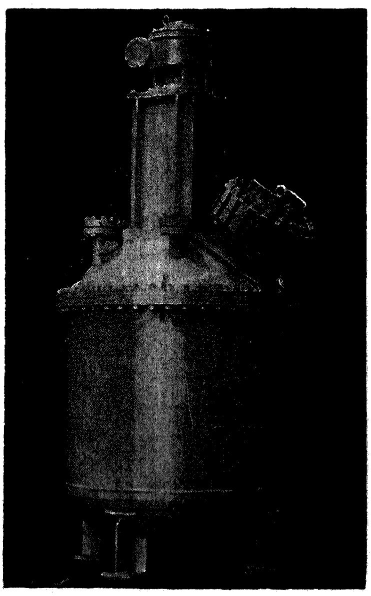


Fig. 1502. Jacketed autoclave 4 ft. 4 in. diameter x 4 ft. 8 in. deep. 2¼-in. plate. 350 lb. working pressure.

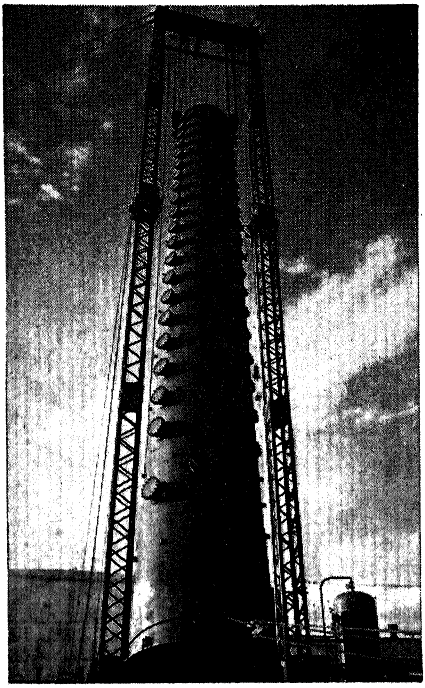


Fig. 1503. Arc welded fractionating column being erected at a refinery. 104 ft. long. 126-in. diameter.

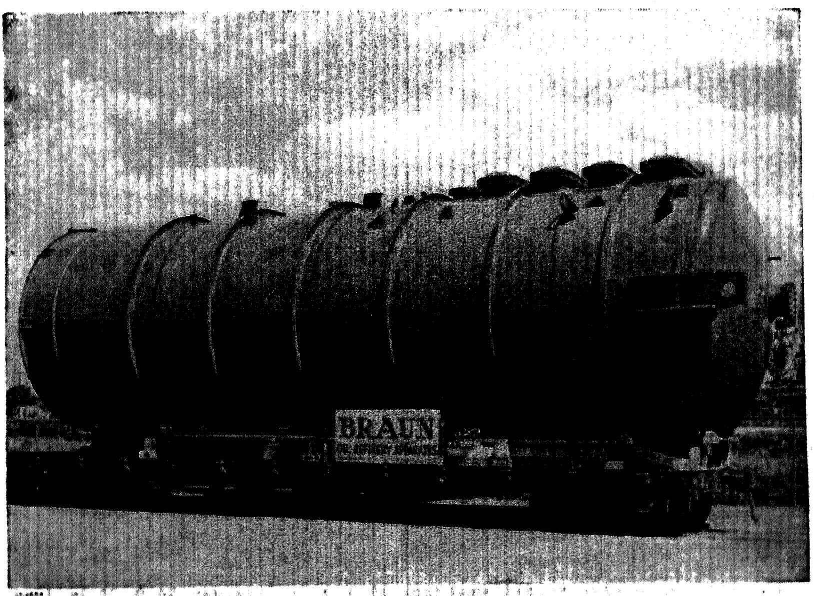


Fig. 1504. Arc welded evaporator for a California refinery. 47 ft. long. 13 ft. diameter.

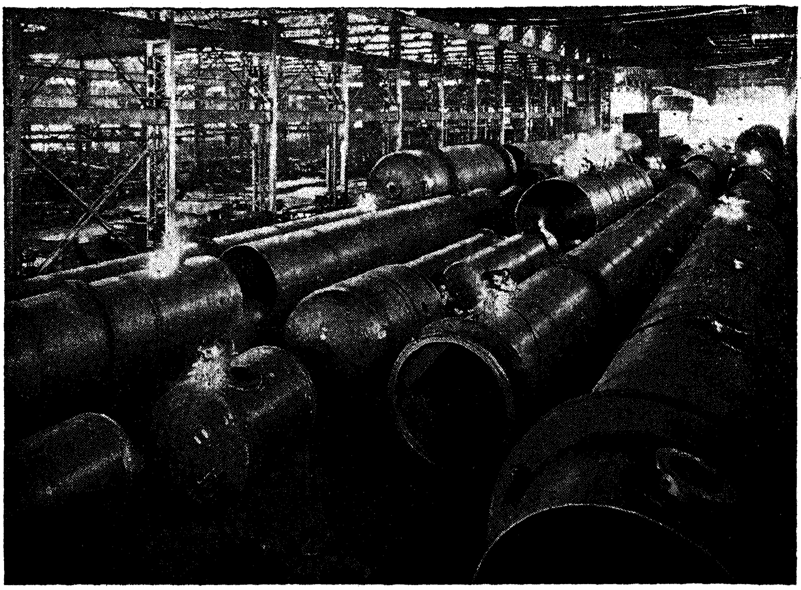


Fig. 1505. View in the welding shop of a large California manufacturer of refinery equipment.

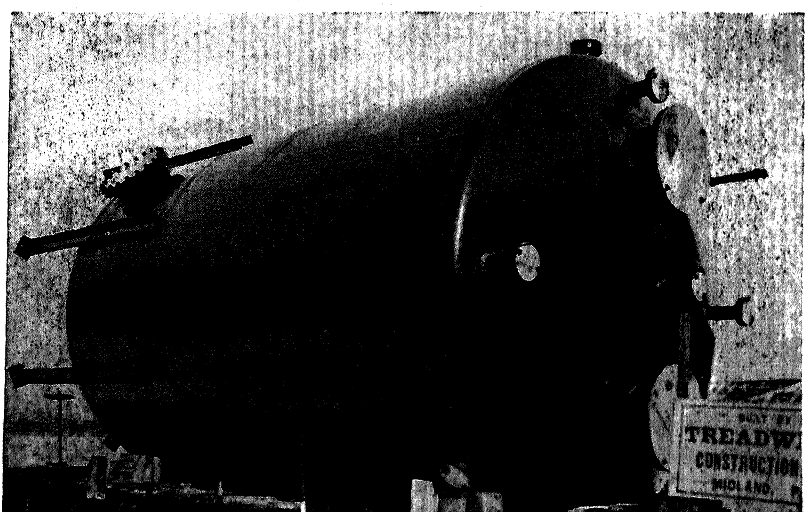


Fig. 1506. Lead lined welded steel tank 10 ft. 6 in. diameter, 20 ft. 10 in. long. For use by a large chemical manufacturer.

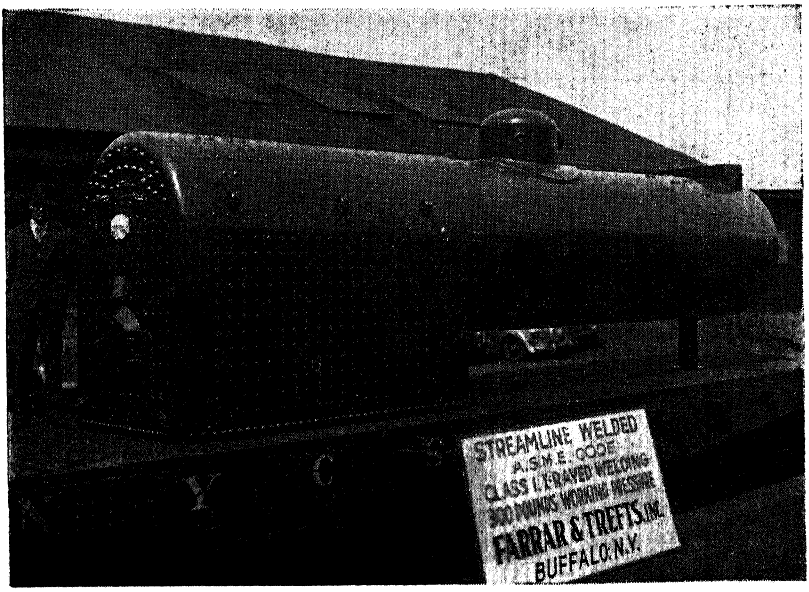


Fig. 1507. Welded steel boiler for oil field service meets A.S.M.E. U-68 requirements. For 130 hp., 300 lbs. working pressure. Eliminates leaks common to riveted boilers of this type and reduces weight 10%. Welds were produced with Type C deep groove electrode and were X-rayed.

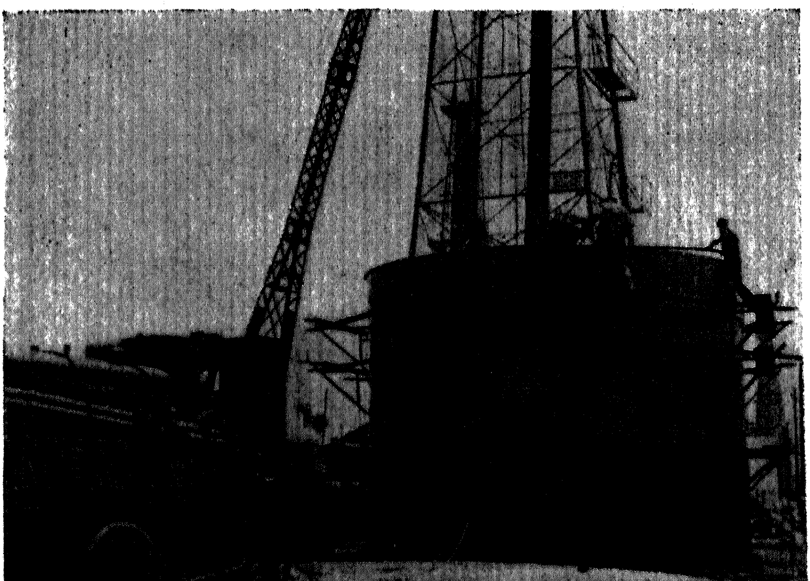


Fig. 1508. Erecting a 1000 bbl. crude oil storage tank in California oil field.

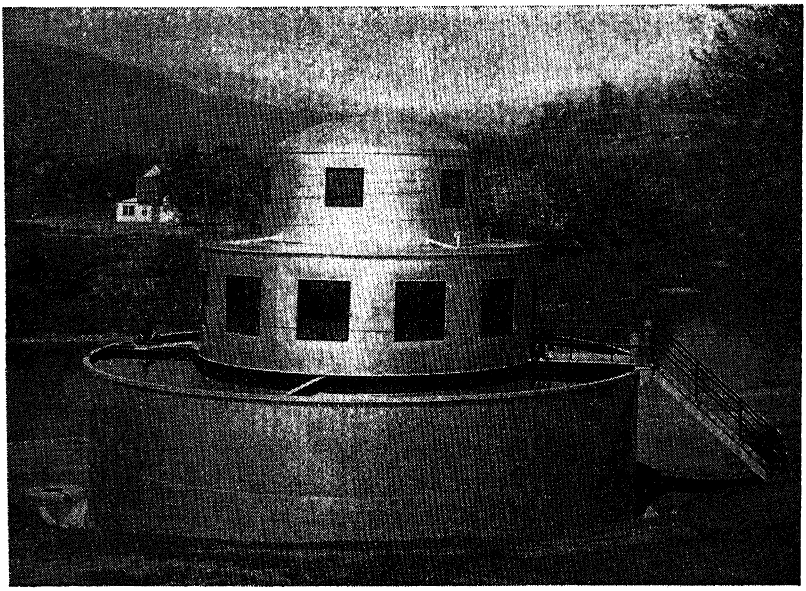


Fig. 1509. Water filter plant of 720,000 g.p.d. capacity fabricated from arc welded steel.

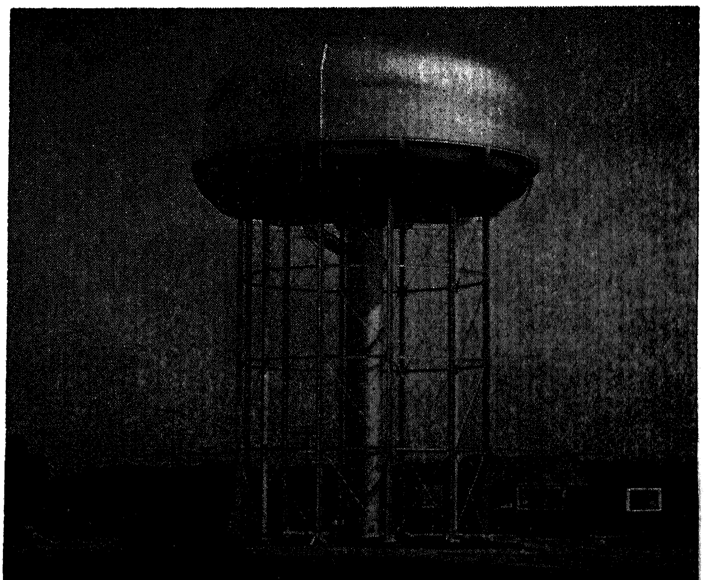


Fig. 1510. Radial cone design elevated water tank of 1½ million gallon capacity of welded steel construction. Total height 103 ft. 6 in.

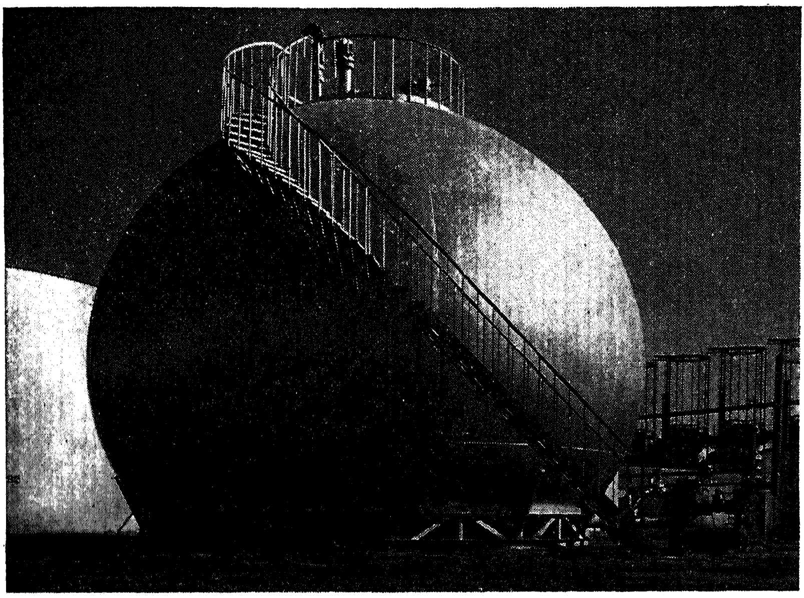


Fig. 1511. 3000 bbl. Hortonsphere—one of several such tanks at the new refinery illustrated in Fig. 1312.

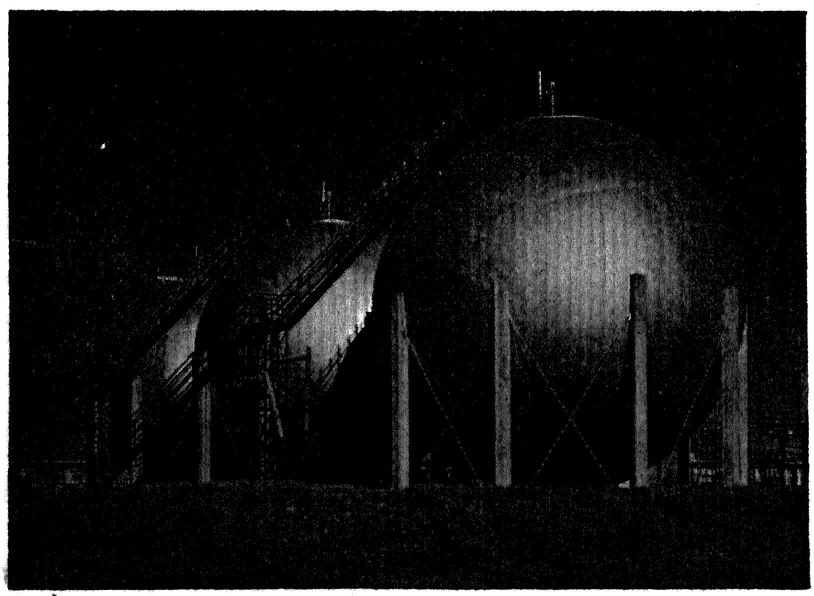


Fig. 1512. Three 12,500 bbl. Hortonspheres of all welded steel construction for operation under 50 lb. pressure in a large refinery in south-east Texas.

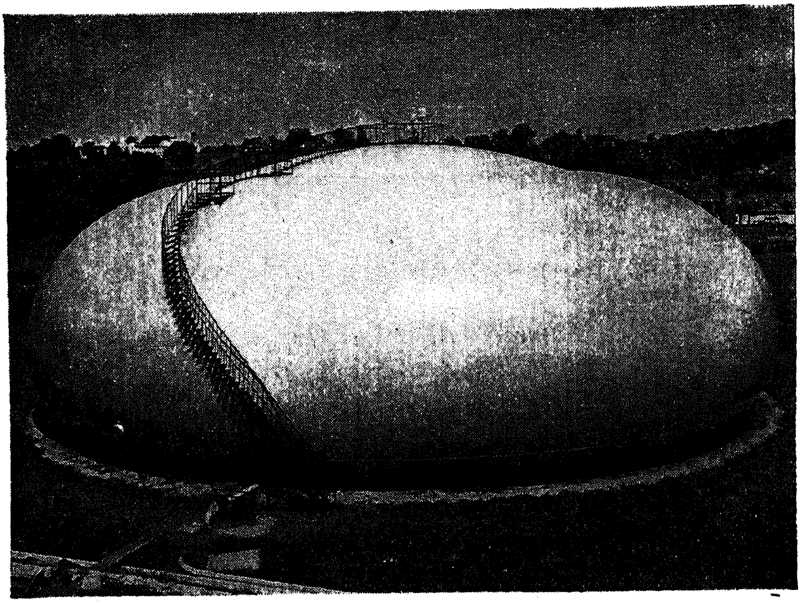


Fig. 1513. 80,000 bbl. Hortonspheroid of all welded steel construction. Diameter 132 ft., height 40 ft.

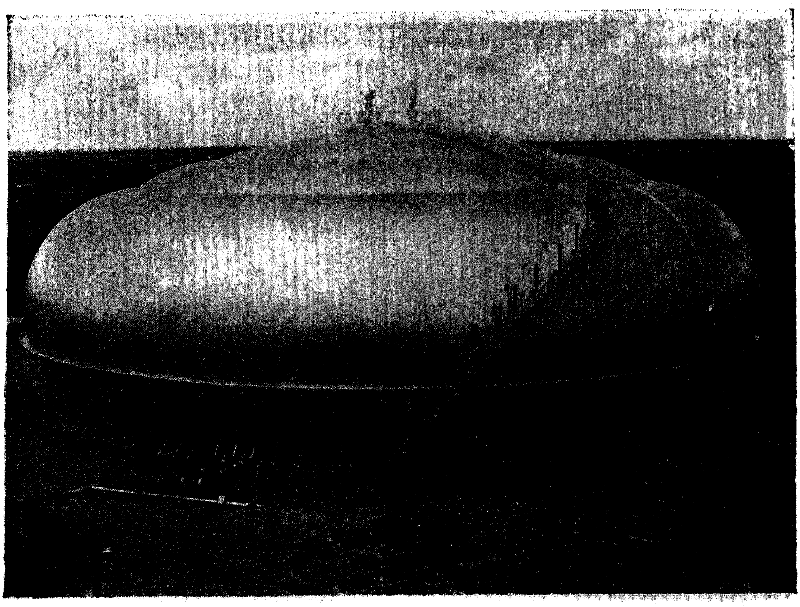


Fig. 1514. 100,000 bbl. Hortonspheroid of all welded steel construction. Located in southern Texas.

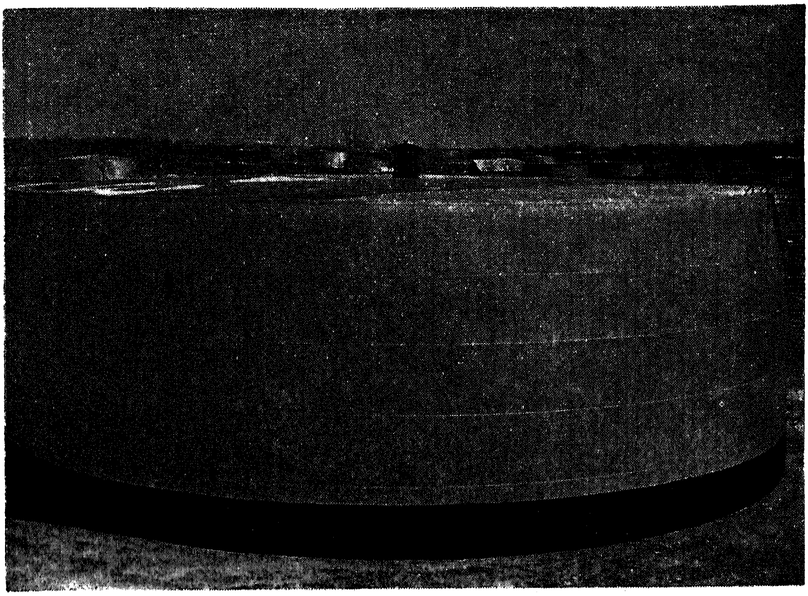


Fig. 1515. One of four 80,000 bbl. oil storage tanks with Wiggins breather roof. Diameter 120 ft., height 40 ft. All welded steel construction.

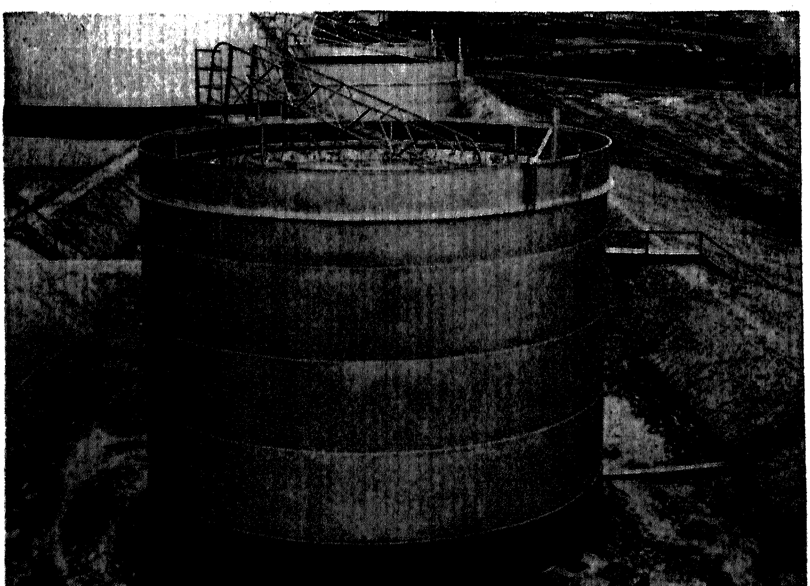


Fig. 1516. 1500 bbl. and 2300 bbl. welded steel oil storage tanks with Wiggins pontoon roof.

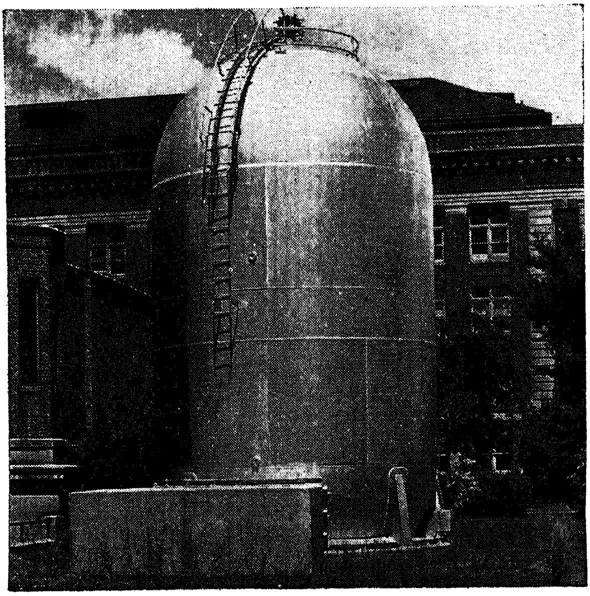


Fig. 1517. Atom buster of all welded steel construction used in the high voltage studies of atomic structures. 21 ft. long, 9 ft. diameter.

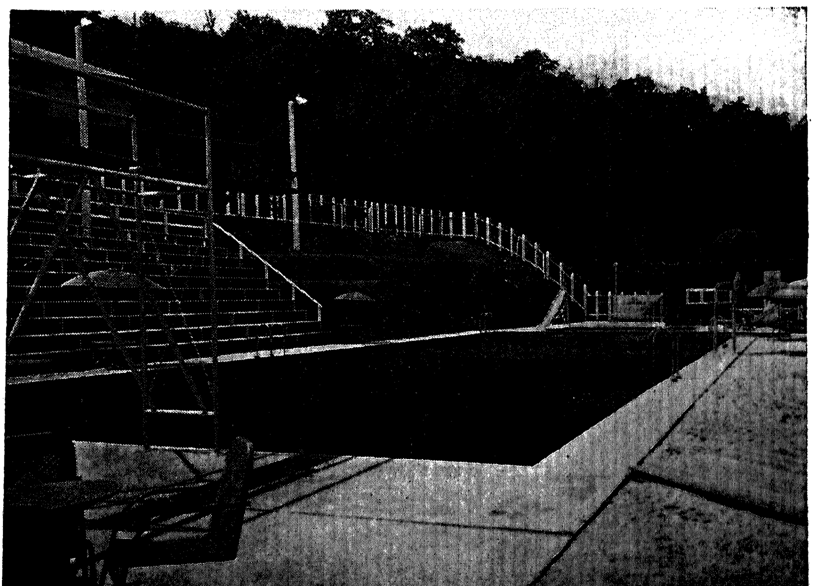


Fig. 1518. Arc welding is used extensively in the construction of swimming pool tanks. This arc welded tank, 100 ft. long by 40 ft. wide, is located at a remote mountain resort. Bottom and side plates are ¼-in. except at deep end where they are 5/16-in. Plates are supported on and are stiffened by I beams.

Tools and Dies

Hard-facing by means of arc welding with tool steel electrode (see Page 361) is used extensively in the building of tools and dies from mild steel and in the reclamation of worn equipment of tool steel construction. A simple example of the use of mild steel stock and tool steel electrode is illustrated in Fig. 1519. This shaper tool was built at a cost of 25c. This method, applied to the building of a stamping die is shown in Fig. 1520.

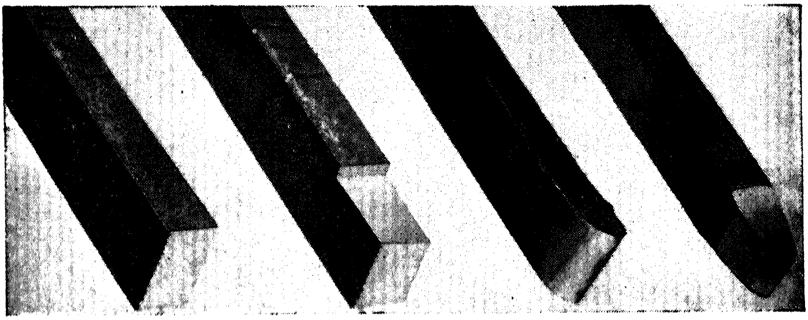


Fig. 1519. Shaper tool made from scrap stock by hard-facing with tool steel electrode and dressing in the usual manner. From left to right: Mild steel shank, prepared shank, hard-faced and dressed tool. Required thirty minutes. Outwears regular tool steel knife costing ten times as much.

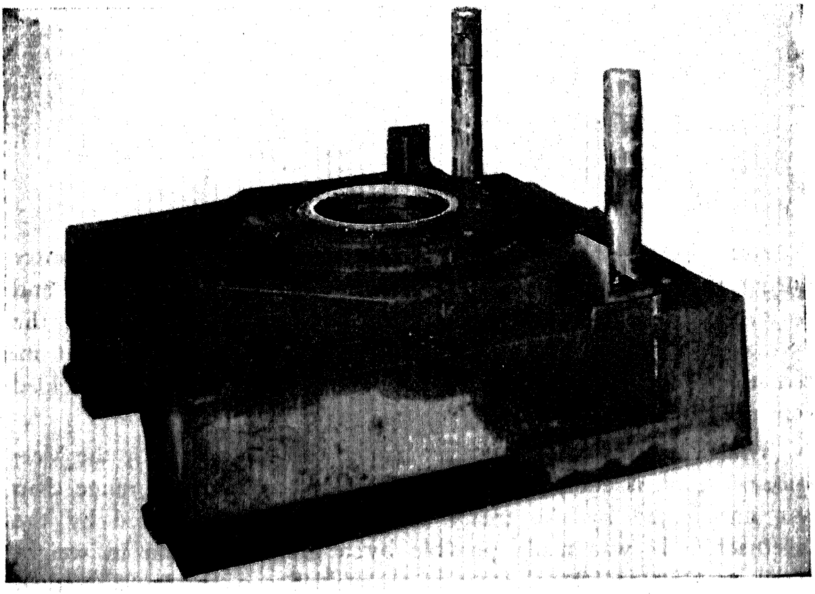


Fig. 1520. Blanking die, built from mild steel plate, hard-faced with tool steel electrode around cutting edge, ground to proper dimensions and welded to die base. Applications such as this save 50% over conventional method of using tool steel throughout.

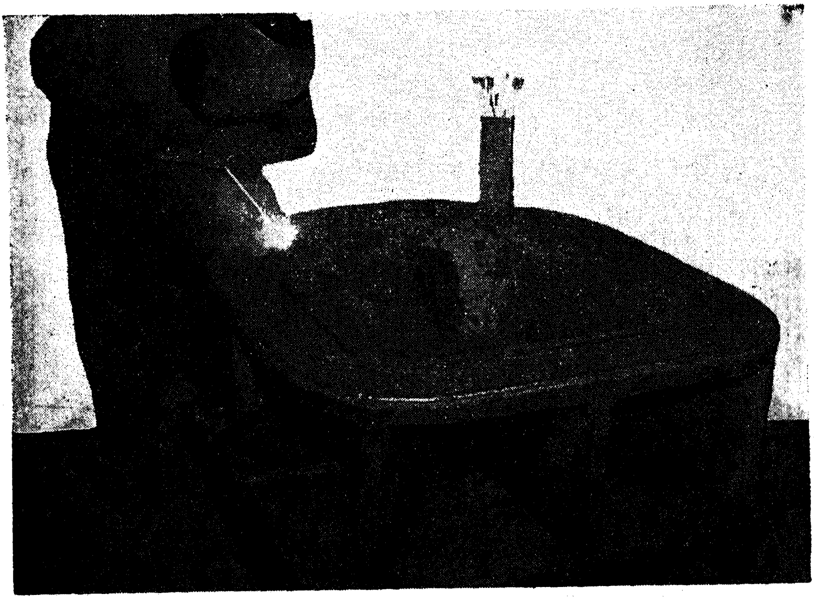


Fig. 1521. Reclaiming wheelbarrow stamping die by building up worn face with tool steel electrode. Deposit is then ground to a flat, smooth finish. Required 80 lbs. of electrode and 100 hrs. of labor. Saved $1200 per die.

Watercraft

Arc welding was first applied to ship construction in this country during the World War. While the use of the process spread and flourished, it was not until the German government launched the "pocket battleship," "Deutschland," illustrated in Fig. 1522, that international attention was focussed upon the efficiency of arc-welded ship construction.

The "Deutschland,"* a cruiser limited to 10,000 tons by the Versailles Treaty, is equipped with guns of greater size and range than was anticipated by the treaty. This advantage possessed by the "Deutschland" was made possible by a great reduction in weight which was effected by the use of arc-welded construction instead of riveted construction. An estimated saving of at least 3% in cost and 17% in weight was made possible by arc-welded design.

*Renamed in 1940, "Luetzow."

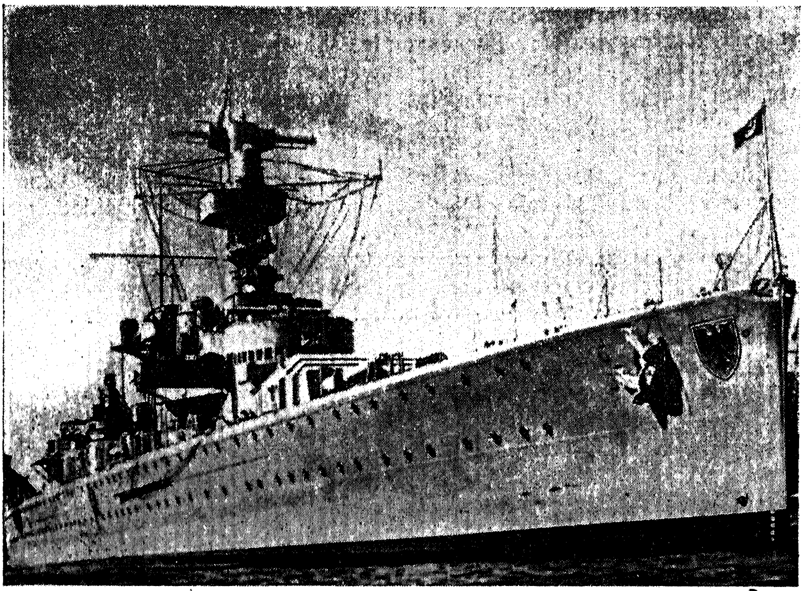


Fig. 1522. The speedy, heavily-gunned "Deutschland", one of three (originally) German "pocket battleship". Arc welded construction kept her within 10,000 ton treaty limitations and permitted extra speed and armament.

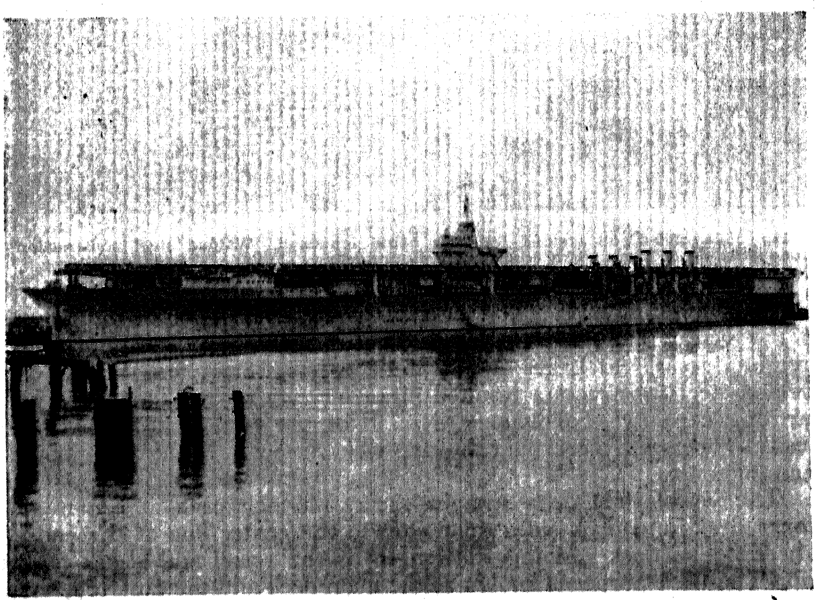


Fig. 1523. Aircraft carrier "Ranger" contains more than 225 miles of welding.

The newest United States naval vessels contain a great deal of arc-welded construction. For example, the decks, bulkheads, masts, and practically all of the piping and many miscellaneous parts are fabricated by the electric arc. Blisters have also been applied to some of the older naval vessels by the electric arc process. Some of the latest type submarines are built almost entirely of arc-welded construction. The United States Navy's aircraft carrier "Ranger", contains more than 225 miles of welds produced by the shielded arc process. See Fig. 1523.

Recently naval lighters and auxiliary vessels, also tug-boats, have been entirely fabricated by arc welding. Many parts of tankers and merchant marine vessels also are now being built of arc-welded construction.

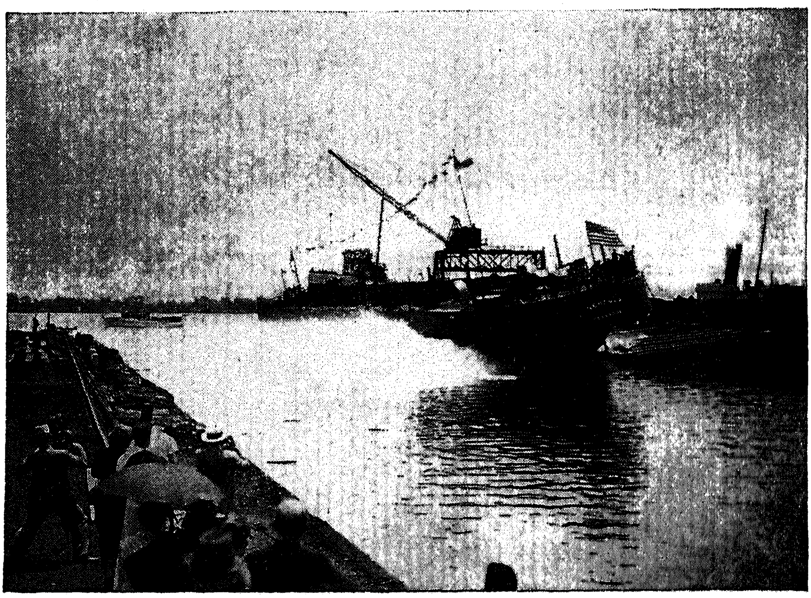


Fig. 1524. 300-ft. all welded freighter being launched. Welded steel construction made possible 300 tons extra cargo carrying capacity.

An interesting example of the arc welded construction of freighters is the vessel illustrated in Fig. 1524. In the case of this 300-foot freighter for Great Lakes and Atlantic coast-wise service, the use of welded steel construction resulted in an increase of 300 tons in cargo carrying capacity. Following are some of the facts concerning this vessel—one of a fleet built by arc welding for a large automobile manufacturer.

The vessels include a straight sheer, a 6-inch peak at center of upper deck, and deck sides rolling up to the center line at the ends. There is one deck running full length of the vessel and also a tank top. The deck proper is known as the main deck and the tank top, the lower deck. The vessels have a six-inch tumble-home from the 12 ft.

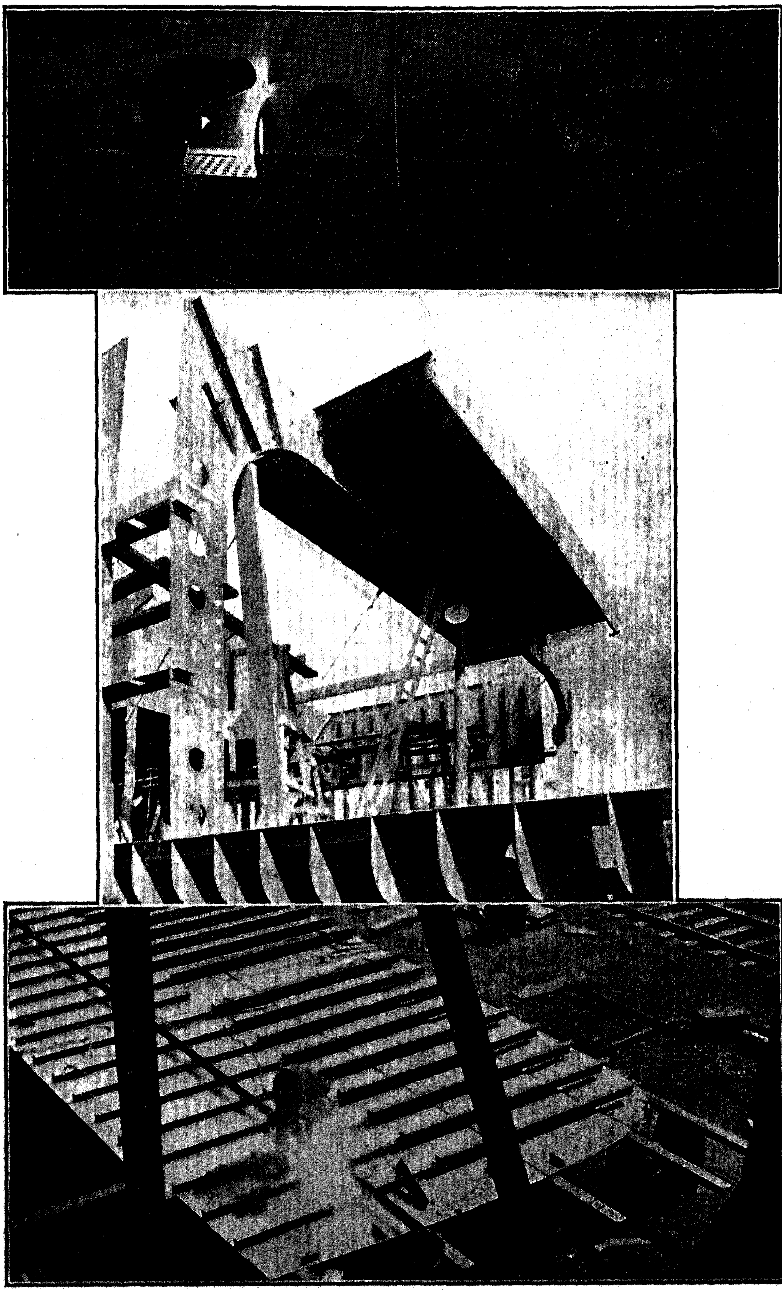


Fig. 1525. Top: Shop fabrication of flooring for 300-ft. all welded freighter. Center: Prefabricated sections in place. Bottom: Fabrication of bulkhead.

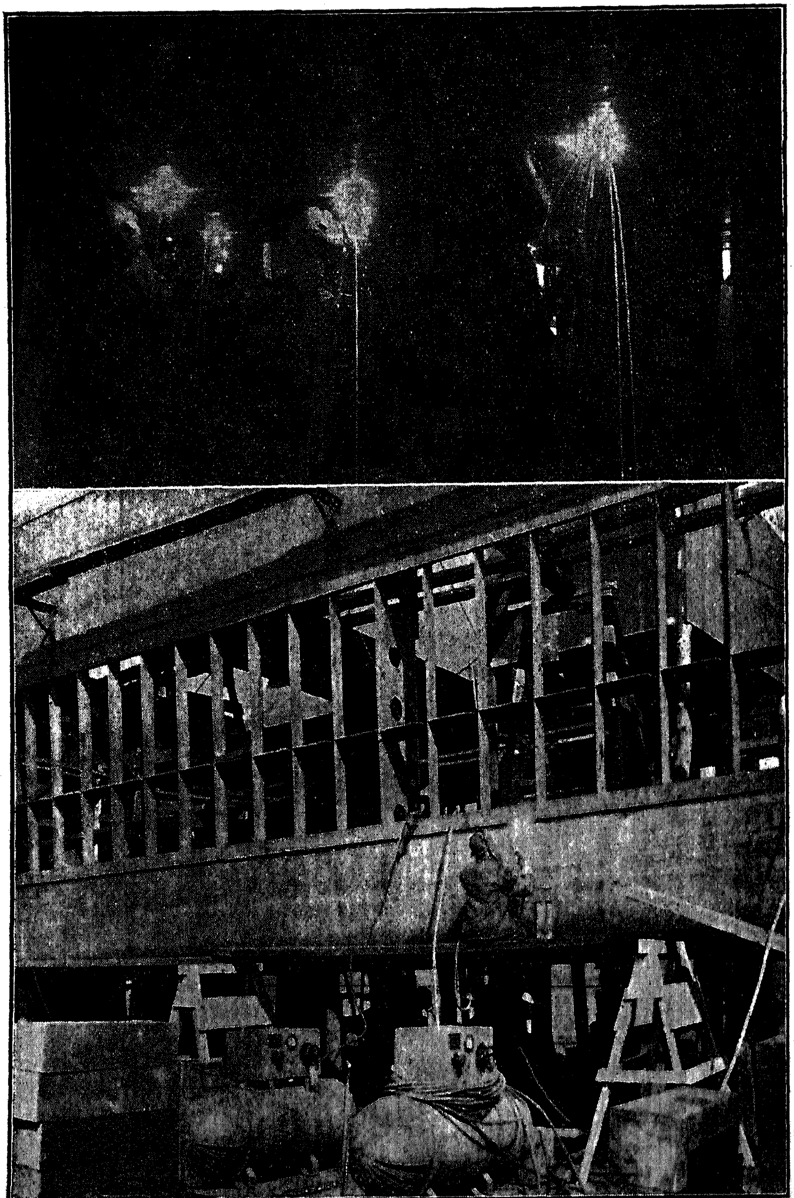


Fig. 1526. Erection views in construction of 300-ft. welded freighter. Top shows welding of the bottom hull plating. Bottom view shows welding on the side of the hull.

6 in. water line to the deck. The machinery space is at the aft end with quarters for all the crew except officers on the main deck above the machinery space. The steering engine space is aft of the engine space. Three cargo holds, served by nine hatches, 12 ft. by 28 ft., are located forward of the machinery space. Officers' quarters, ballast tank and chain locker are forward of the cargo holds. The pilot house is located forward and is electrically lowered for passing under bridges. Masts and stanchions are hinged. The boat davits, ventilators and stacks are arranged for removal. Fuel oil is carried in wing tanks in the engine room. Each vessel has two rudders and two steel fenders, 6 in. by 1 in. running the length of the vessel.

A general view of construction of the 300-ft. freighter is shown in Fig. 1524. Wherever possible, advantage was taken of fabricating sections of the hull as complete units. Sections which were pre-assembled and welded before erection include all floors (Fig. 1525), bulkheads, sheer strake plates welded to frames, main tack stringers, decks, machinery foundations, sky lights, transoms and other assemblies of hull structures. In Fig. 1525, the pre-fabricated bridge, pilot house and transom section are shown in place. Welding views are shown in Fig. 1526.

The general procedure for welding employed in the construction of these freighters was to start at the center of the vessel and weld outward, forward and aft from this point.

Erection was maintained about a day ahead of the welding. The butt welds for each plate were completed before the next plate was fixed by any seam welding. Any contraction which might occur athwartships in the bottom plating was adjusted in the lapped seams. One strake was left off the tank top at each side until all piping in the double bottom was in place and the width of the plates adjusted to suit. Any contraction longitudinally was adjusted in the last dead-flat plates at each end.

The midship arch and the two midship bulkheads were erected and plumbed when the tank construction had reached the proper point. At that time, two sheer strake plates at each side with attached frames were erected and the frames welded to the tank top. Bilge plates were then erected and welded as fast as the frames were in place. The deck assembly was erected on the midships arch and the two bulkheads.

Downhand welding was used wherever possible. However, with the transverse system of framing, the welding of tank top to floor throughout the ship and deck plating to beams in the ends must be overhead. The finish welding was started at the precise center of the vessel and progressed outward, port and starboard, and fore and aft, leaving material ahead of the welding free to move and leaving no unfinished seams or welds which might cause excessive strain or distortion when they were welded.

Other watercraft of arc welded steel construction includes barges of many types, yachts, cabin cruisers, houseboats and small motor craft. A number of these are shown in the accompanying illustrations.

Arc welding is also used extensively for ship maintenance. A number of applications are illustrated on the following pages.

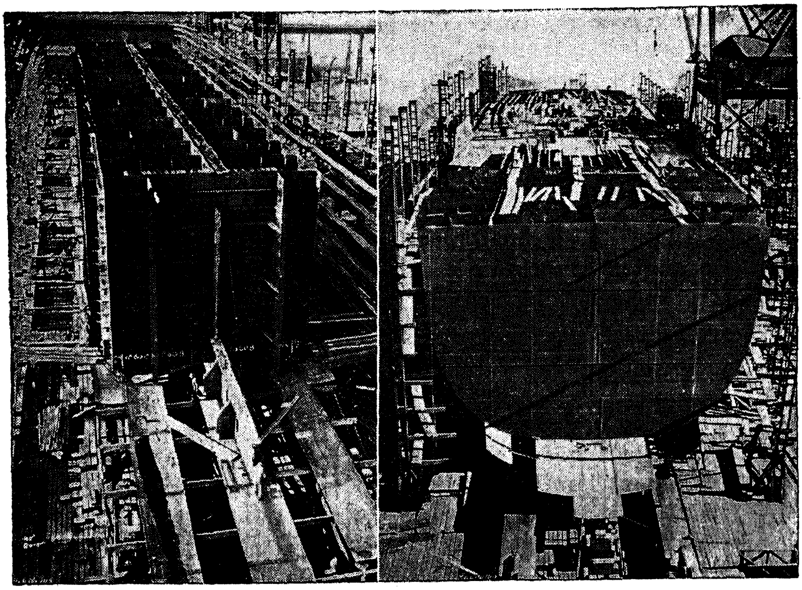


Fig. 1527. This 103,000 bbl. tanker, built for a large oil company, can carry 300 to 400 tons extra cargo because of weight savings made by welding. Welded parts include internal framing between fore and after peak bulkheads, all transfer bulkheads, bottom longitudinals, tank tops, foundations, deckhouses, rail stanchions and hatches.

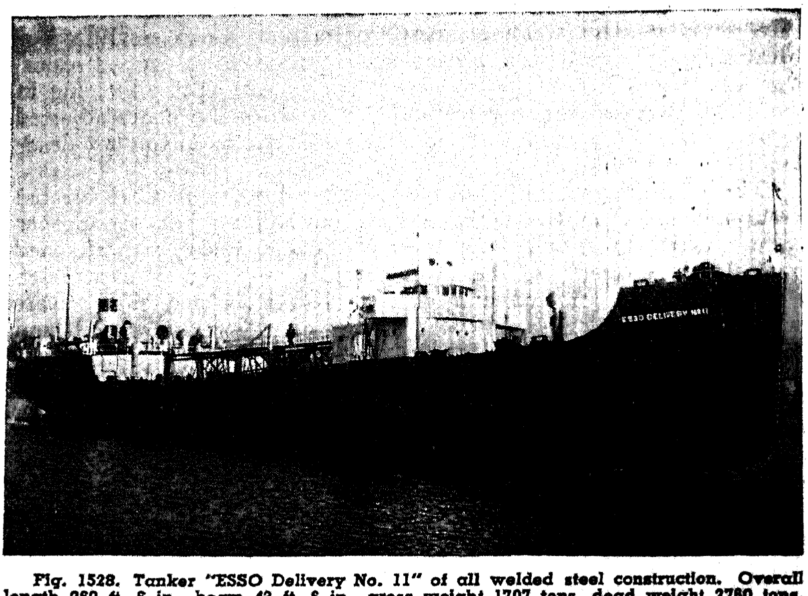


Fig. 1528. Tanker "ESSO Delivery No. 11" of all welded steel construction. Overall length 260 ft. 6 in., beam 43 ft. 6 in., gross weight 1707 tons, dead weight 2780 tons. Cargo capacity 17,010 bbls. 1000 hp. Longitudinally framed deck and bottom with transversely framed sides. Continuous longitudinally stiffened main center line bulkhead. Twelve main cargo tanks with vertically stiffened bulkheads. Sequence of welding carefully worked out to facilitate maximum sub-assembly and erection sequence planned on free-end principle. Welding started amidships on center line at bottom and proceeded forward and aft, outward and upward, to allow structure to have outer ends free of restricting stresses.

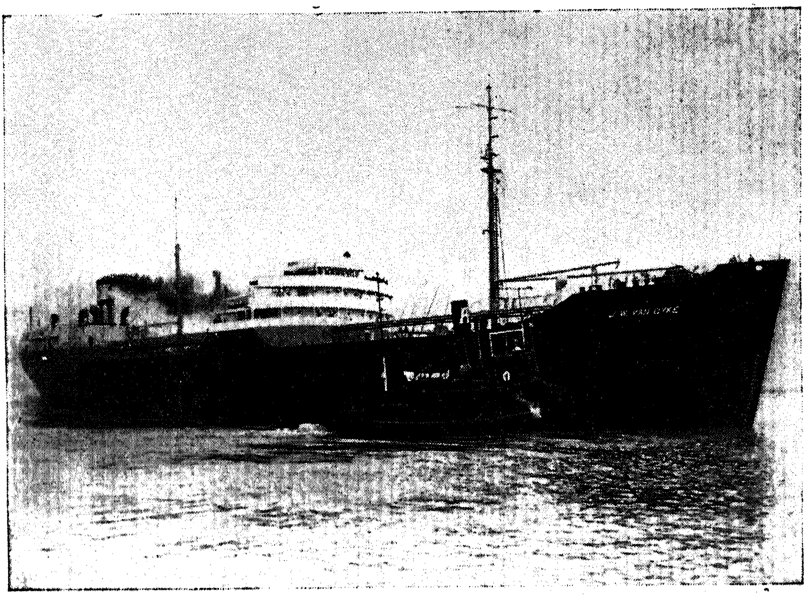


Fig. 1529. Turbo electric tanker "I. W. Van Dyke." Completely arc welded except hull ends. Overall length 543 ft., beam 70 ft., depth 40 ft., dead weight capacity 18,500 tons, cargo capacity 156,000 bbls. Embodies Isherwood longitudinal bracketless system.

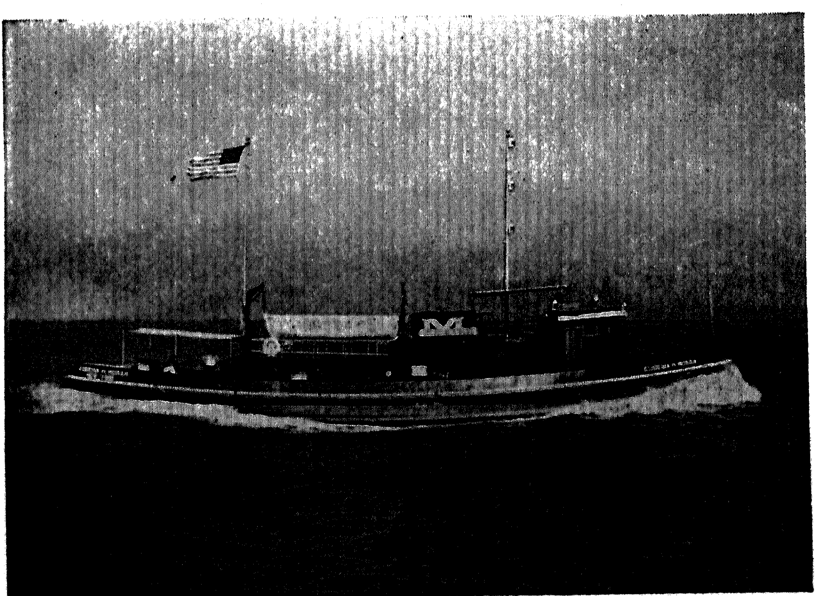


Fig. 1530. Diesel electric tug-boat "Eugenia M. Moran." Overall length 94 ft. 4½ in., beam 25 ft., depth 12 ft. All arc welded construction.

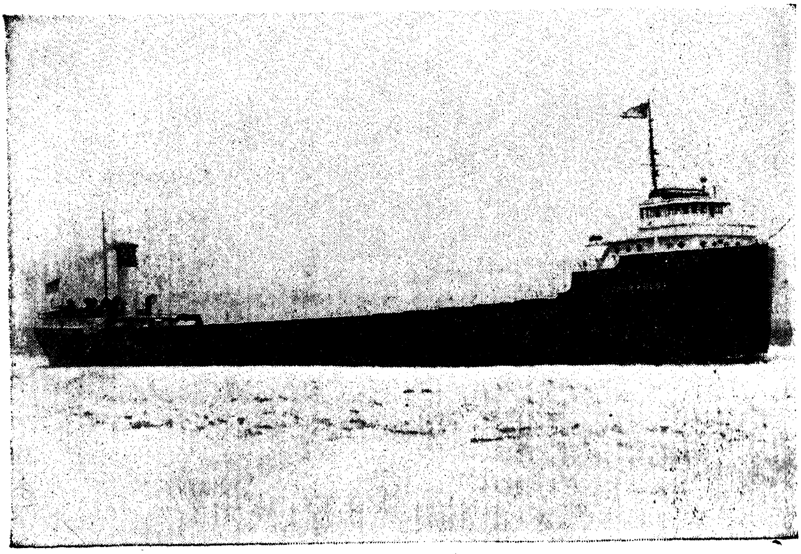


Fig. 1531. Bulk ore carrier "John Hulst." Overall length 610 ft. 9 in. Molded beam, 60 ft., molded depth 32 ft. 6 in., gross tonnage 8245 tons. Tank top, side tanks, house tops, foundations, parts of decks, skylights, stacks and masts are all welded.

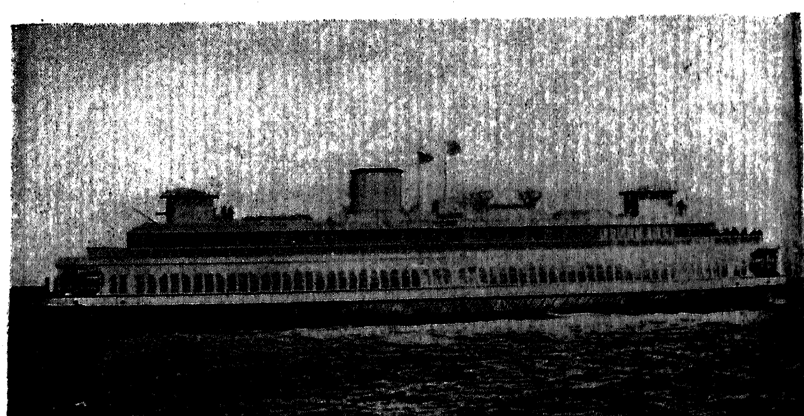


Fig. 1532. Ferryboat "Gold Star Mother." Overall length 267 ft., beam 68 ft., depth of hull 19 ft. 9 in., capacity 3000 passengers and about 30 motor cars. Arc welding used extensively in construction.

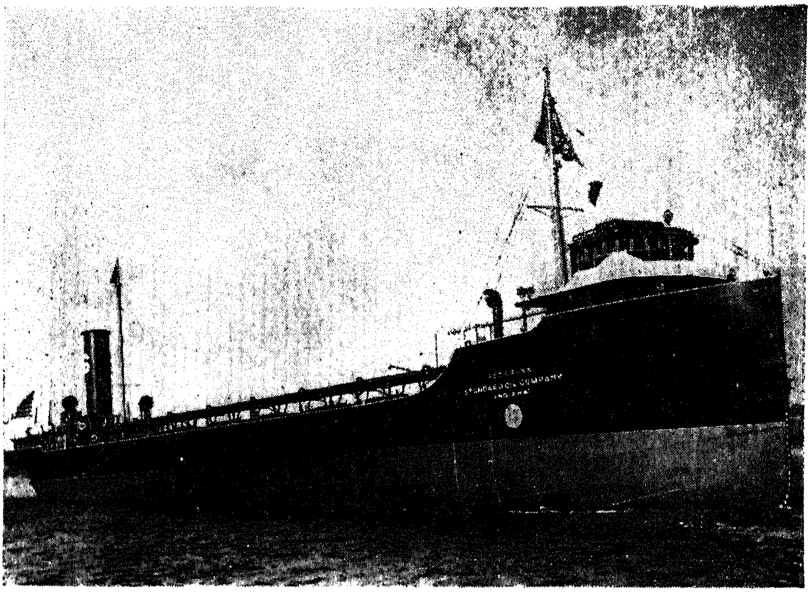


Fig. 1533. Tanker "Red Crown." Overall length 465 ft., molded beam 55 ft., depth 28 ft., dead weight capacity 7682 tons. Interior structure, including bulkheads, tank top and deck houses of arc welded construction.

Fig. 1534. Trawler "Kittiwake." Length 146 ft. 6 in., beam 25 ft. 6 in., depth 14 ft. 6 in., capacity 300,000 lbs. fresh fish. Practically all welded construction except hull.

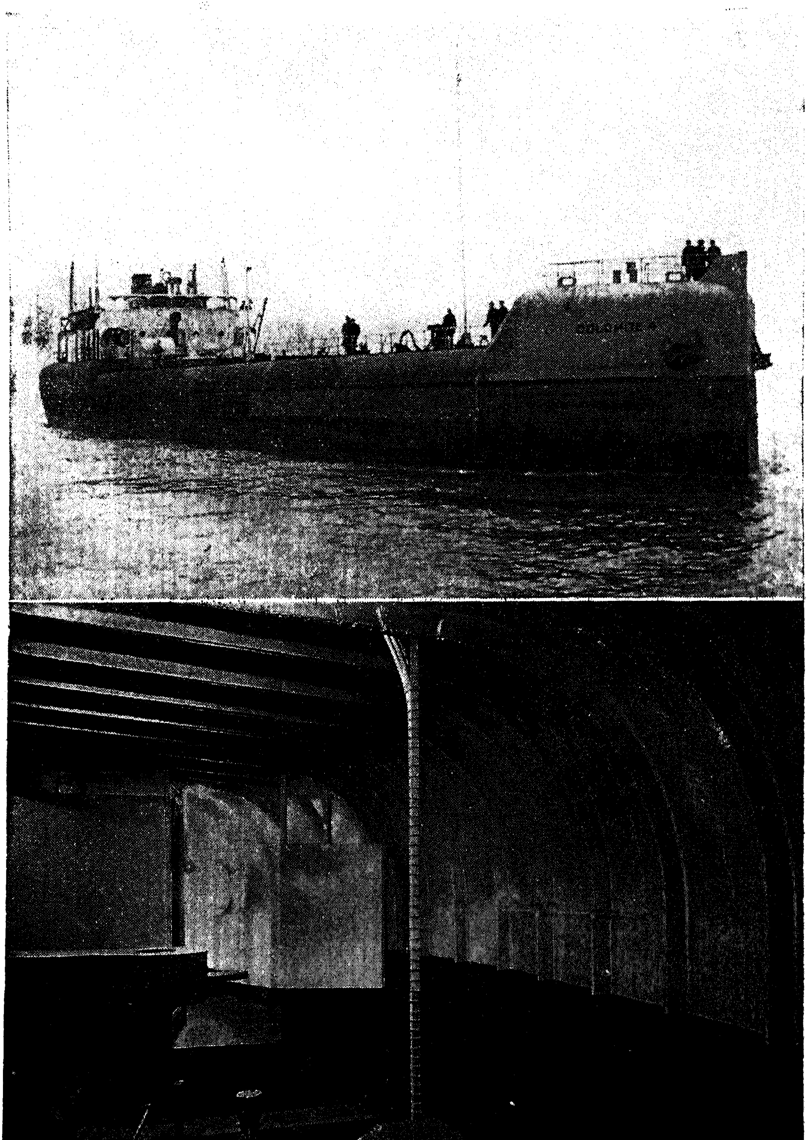


Fig. 1535. Twin-screw Diesel tanker "Dolomite 4." 300 ft. long. Gross tonnage 5500. Classed by Lloyd's with full ocean rating. For canal, lake and coastal service. All welded steel hull fabricated from formed channel sections giving a simplified design of great rigidity, strength and light weight. (See lower illustration.) Cargo tanks are all welded and nickel lined making possible highly satisfactory shipment of wide range of cargoes. Welds on outside of hull joining channels made by tractor type automatic shielded carbon arc welder. Welds on inside joining channel flanges made by manual shielded arc process.

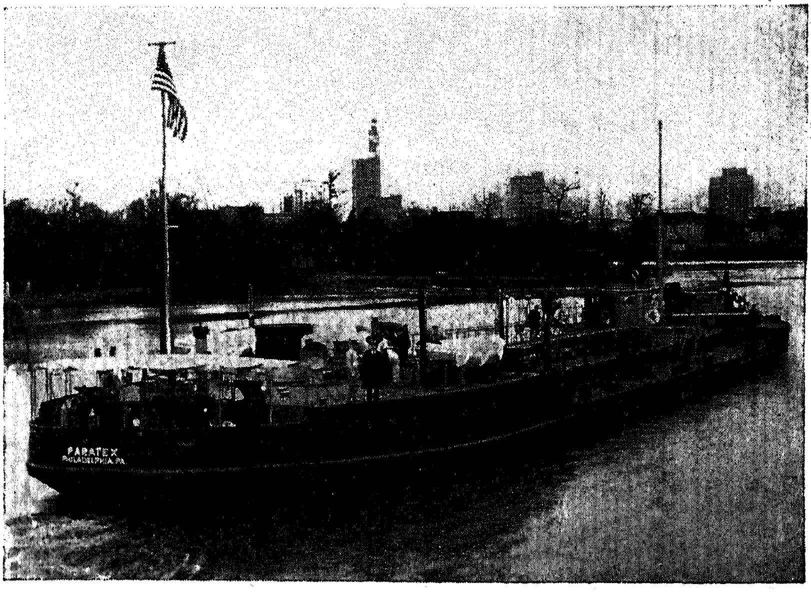


Fig. 1536. Tanker "Paratex" of all welded steel construction.

Fig. 1537. Tanker "E. I. Henry." High-pressure, turbo electric, 18,500 ton dead weight, 6000 shaft hp. All welded steel construction.

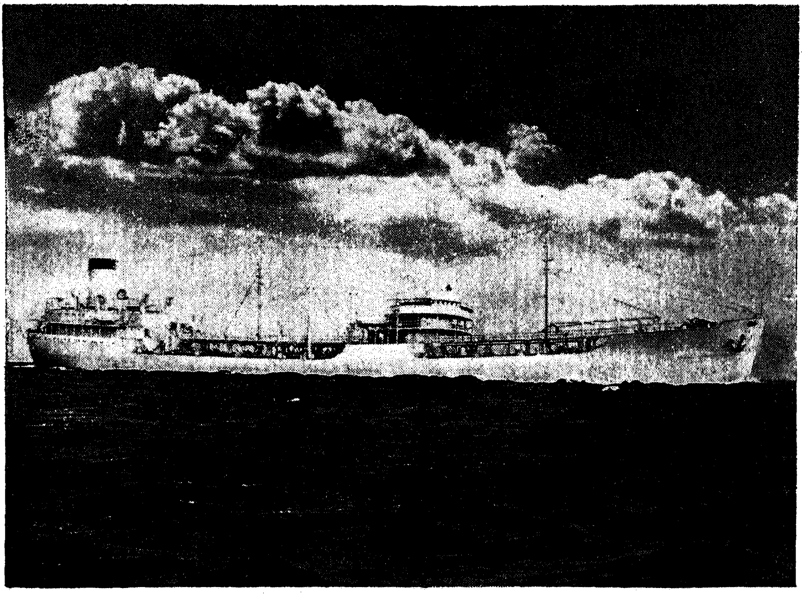


Fig. 1538. Tanker "Cimarron." 18-knot, high-pressure geared-turbine, 18,230 ton dead weight. Interior of hull and super structure are all arc welded construction.

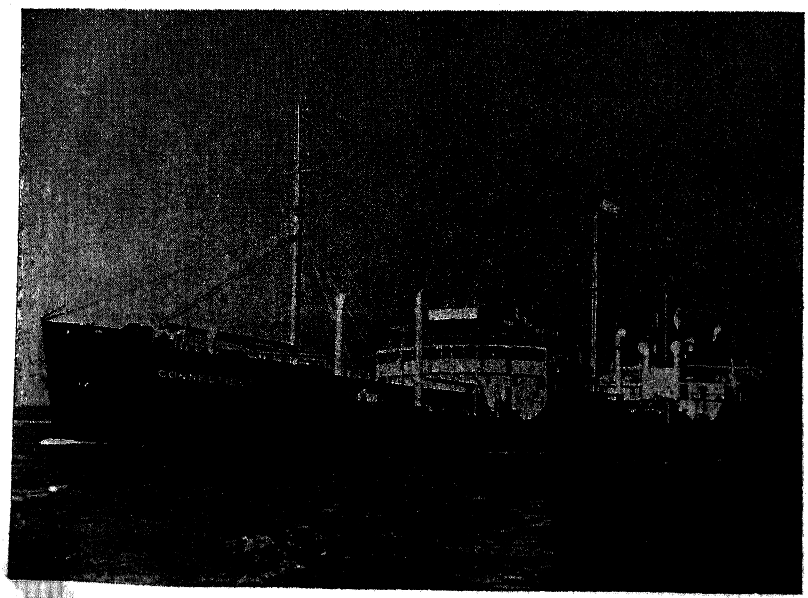


Fig. 1539. Tanker "Connecticut." 13½-knot, high-pressure, geared-turbine, 12,785 ton dead weight. Bulkheads and super structure are arc welded.

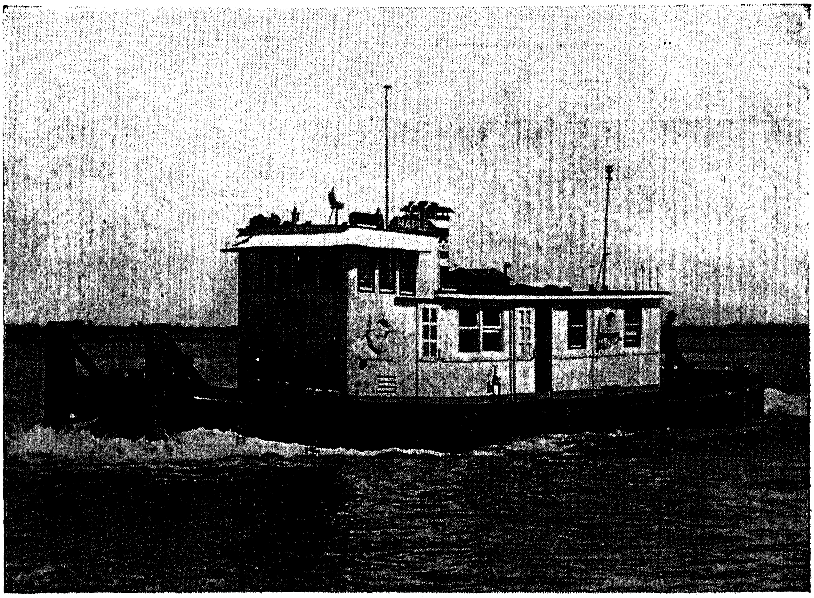


Fig. 1540. Dredge tender "Maple." Diesel-powered river tow boat of all welded steel construction.

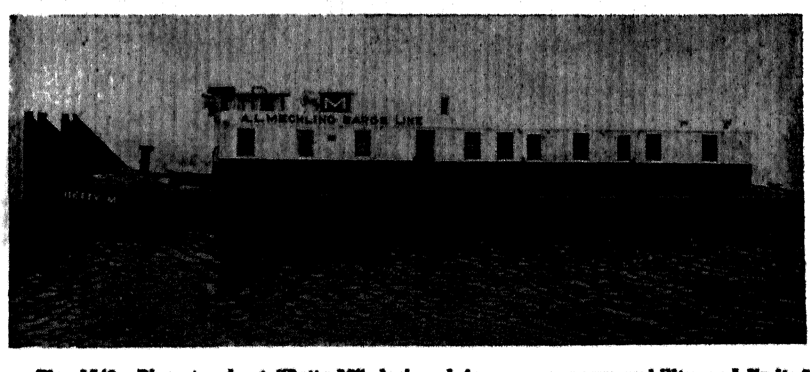


Fig. 1542. River tow-boat "Betty M" designed for easy maneuverability and limited headroom. Hull is 81 ft. 10 in. by 20 ft. by 8 ft. 3 in. Hull plating is 5/16-in. Has retractable pilot house. All welded steel construction.

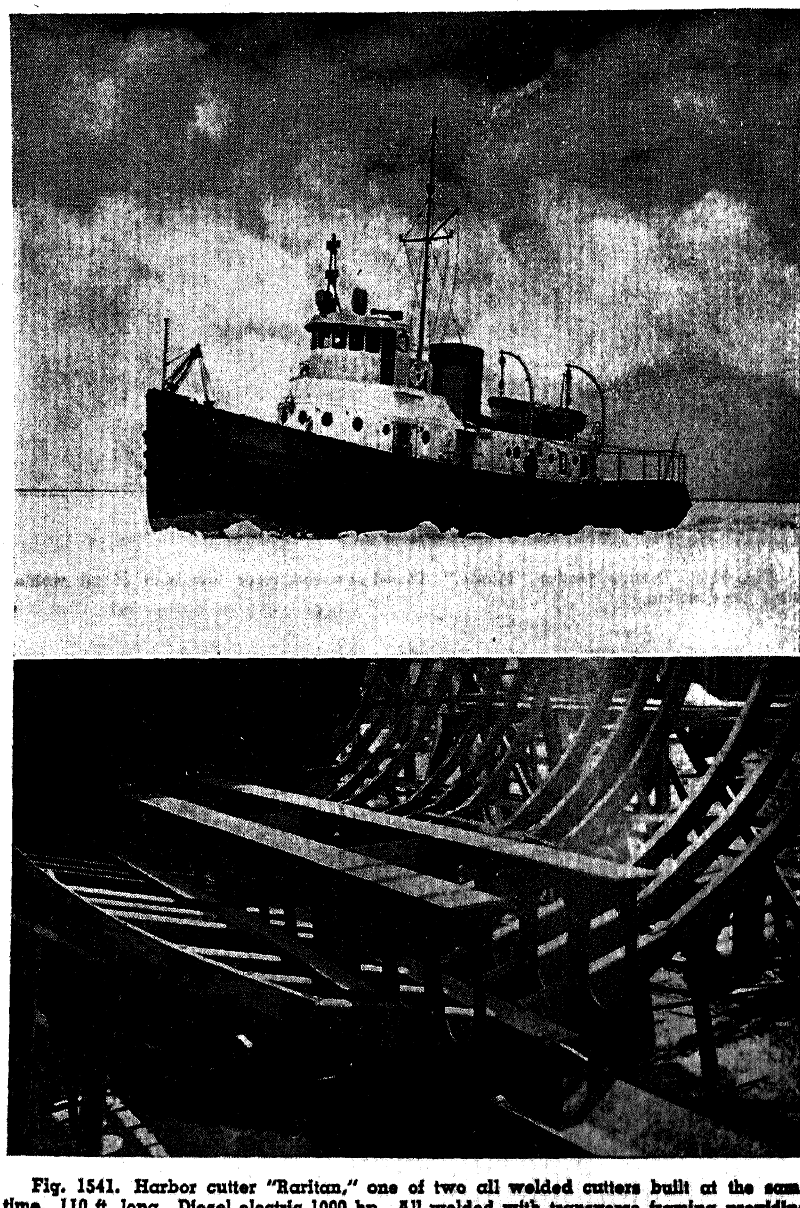


Fig. 1541. Harbor cutter "Raritan," one of two all welded cutters built at the same time. 110 ft. long. Diesel electric 1000 hp. All welded with transverse framing providing exceptional rigidity, permanent tightness and minimum weight. Below: View during erection showing shop fabricated hull structural members.

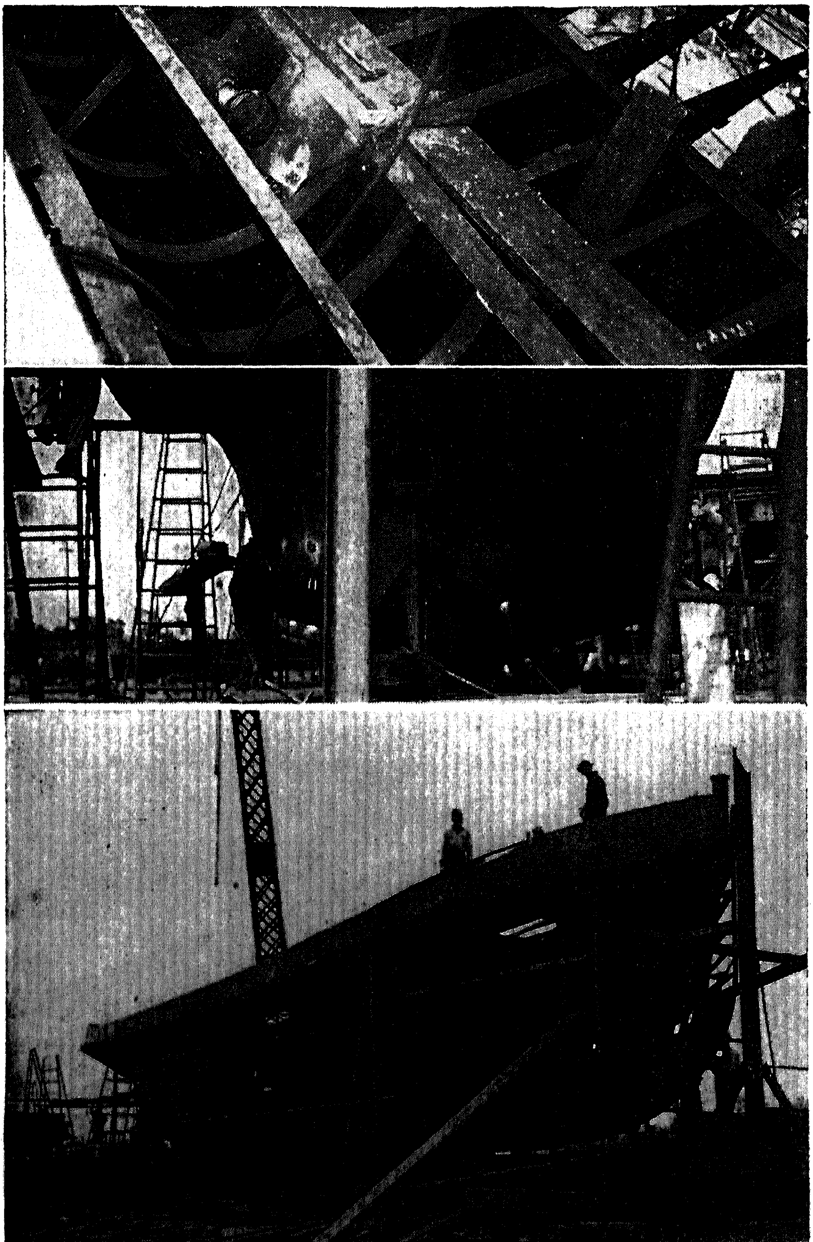


Fig. 1543. Construction views of welded steel tug. 80 ft. by 20 ft. by 9 ft. 6 in.

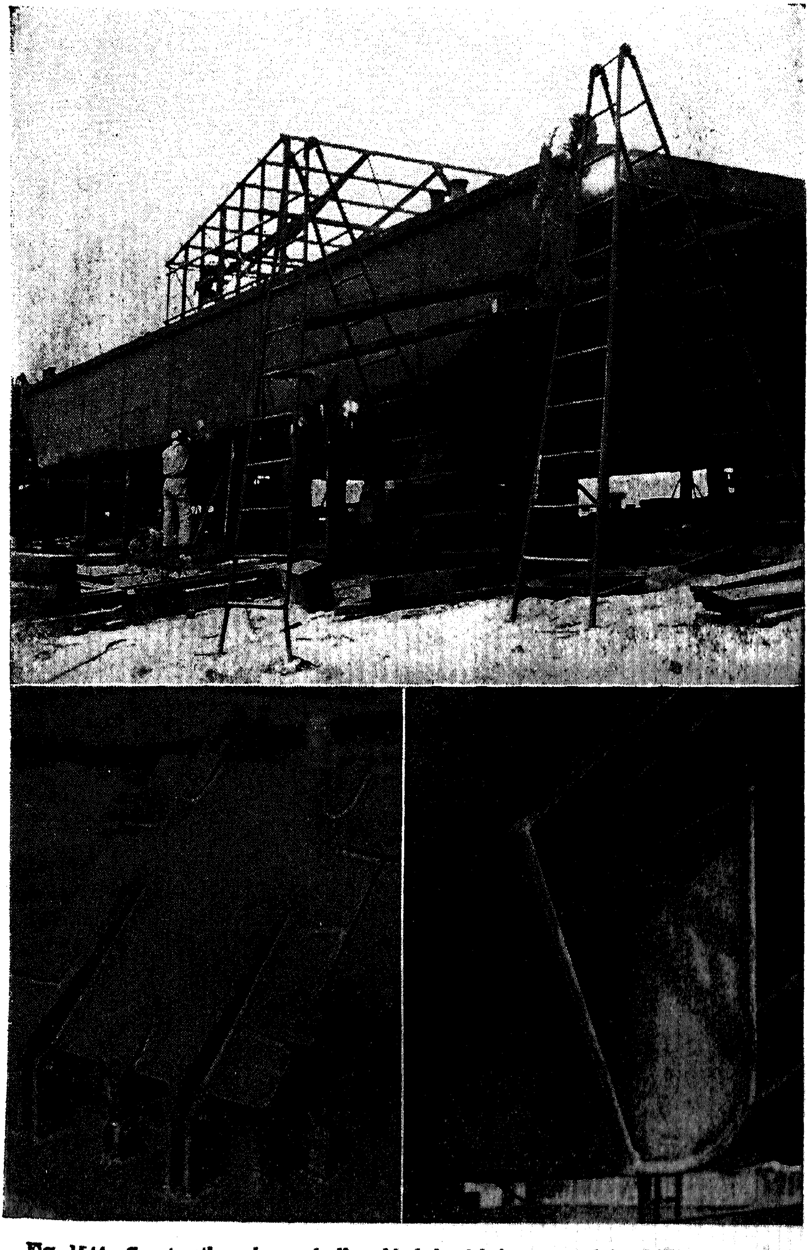


Fig. 1544. Construction views of all welded derrick barge used for drilling operations along the Gulf coast. 70 ft. by 36 ft. by 6 ft. Lower left: Close-up of all welded hatch. Lower right: Construction at stern showing skegs.

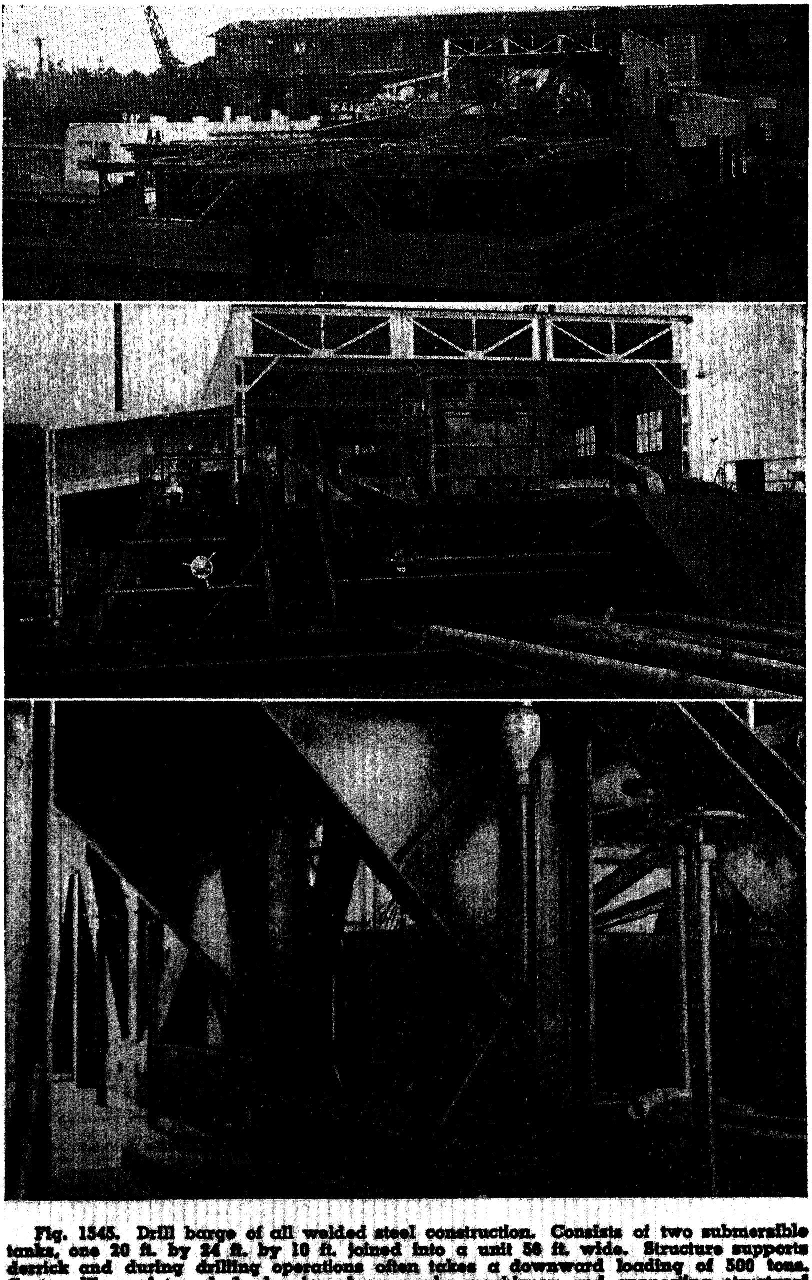


Fig. 1545. Drill barge of all welded steel construction. Consists of two submersible tanks, one 20 ft. by 24 ft. by 10 ft. joined into a unit 56 ft. wide. Structure supports derrick and during drilling operations often takes a downward loading of 500 tons. Center: View of top deck showing draw works machinery and supporting structural members. Below: View on lower deck. These heavy, all welded structural members take a portion of the drilling load and static load.

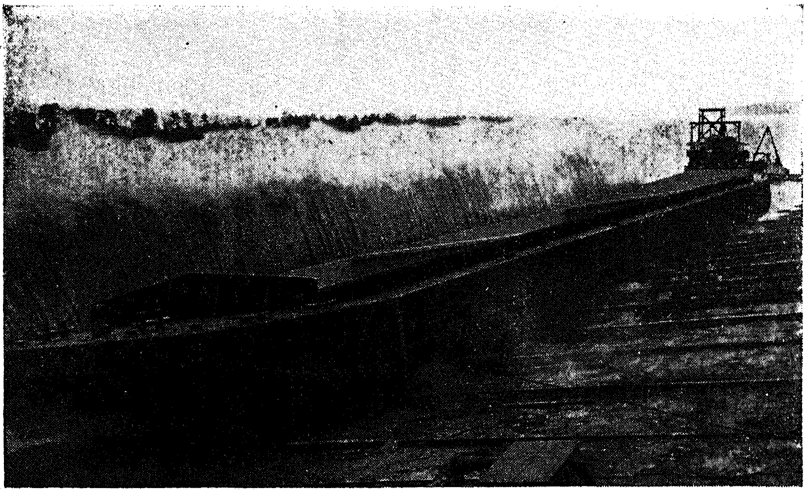


Fig. 1546. All welded river barge being launched. 280 ft. long, 48 ft. wide, 11 ft. deep. Contains 600 tons of steel. At this time, this barge was one of 566 all welded hulls built by this company. Tractor type automatic shielded carbon arc welder used out of doors for many of the horizontal lap and butt welds.

Fig. 1547. Scow for use in Hawaii. Consists of four water-tight all welded sections to facilitate shipping and make possible assembly in the water.

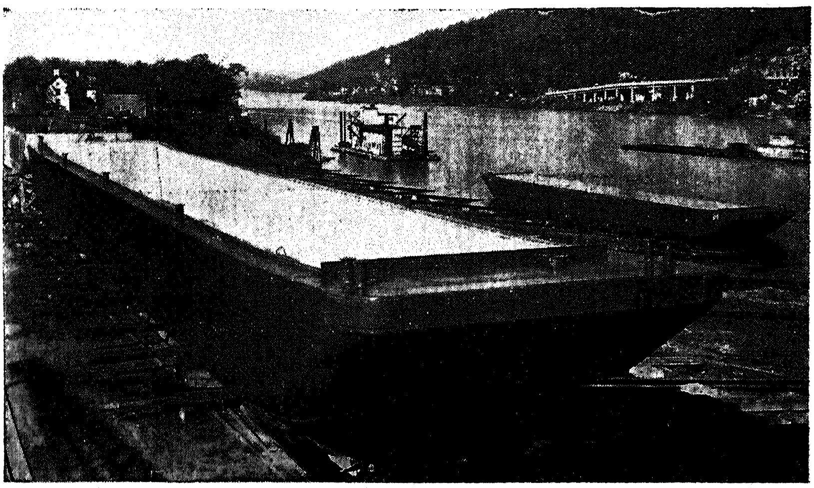


Fig. 1548. Coal barge of all welded steel construction ready for launching. Dimensions: 175 ft. x 26 ft. x 10 ft. 8 in.

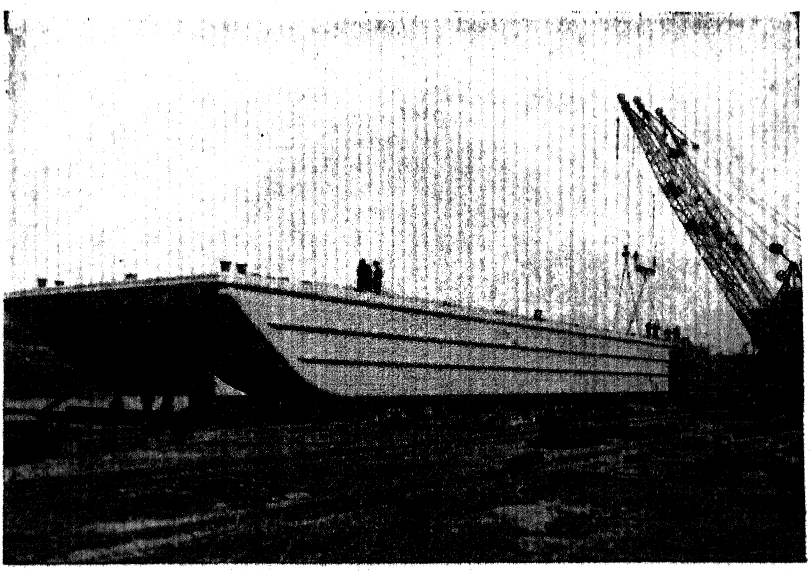


Fig. 1549. Welded steel dump scow ready for installation of machinery. Capacity: 1200 cu. yds.

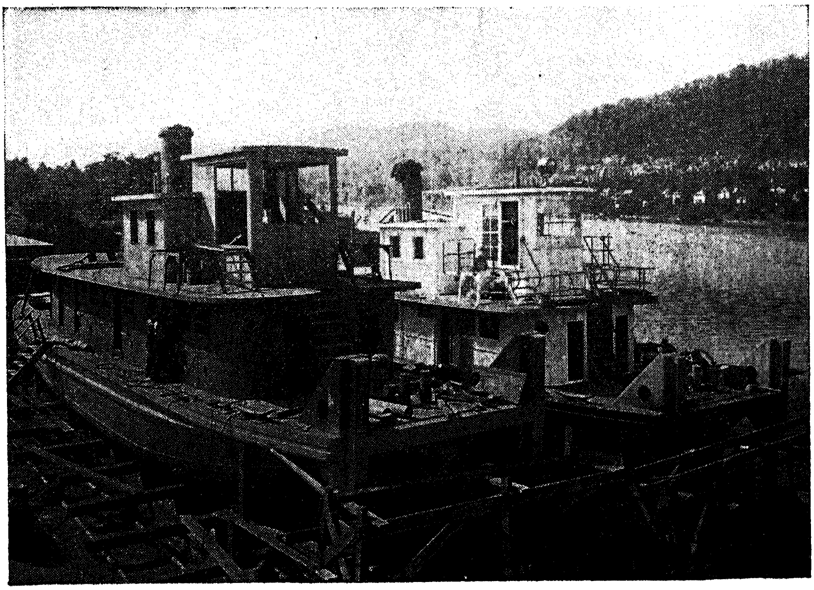


Fig. 1550. Two single screw Diesel tow boats during course of construction. Length overall 94 ft.; beam moulded 21 ft.; depth 14 ft. 6 in.; draft 4 ft. 10 in. All welded steel construction.

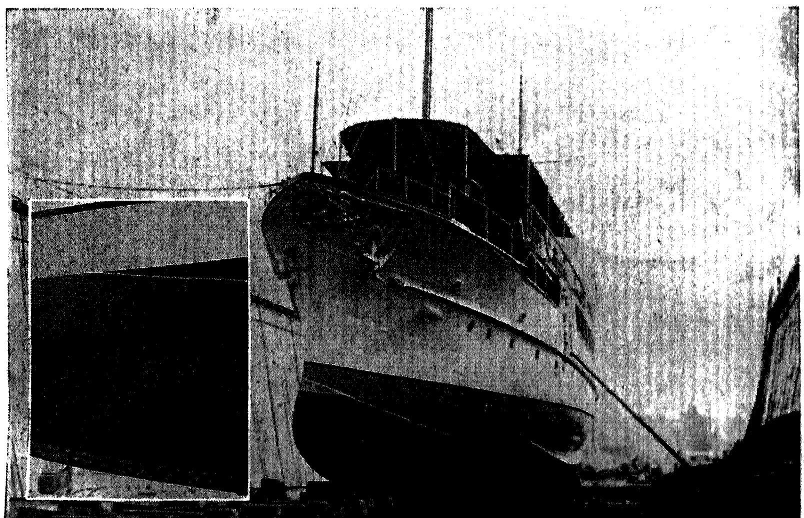


Fig. 1553. Hull of this yacht was baldly corroded below water line. Conventional method of repairing hull by cutting old plating away from frames and riveting on new plates would have cost $45,000. New steel plate was added to the corroded hull at a cost of $15,000. Careful check on weight of material added showed an increase of ten tons. Increased draft 2¼ in.

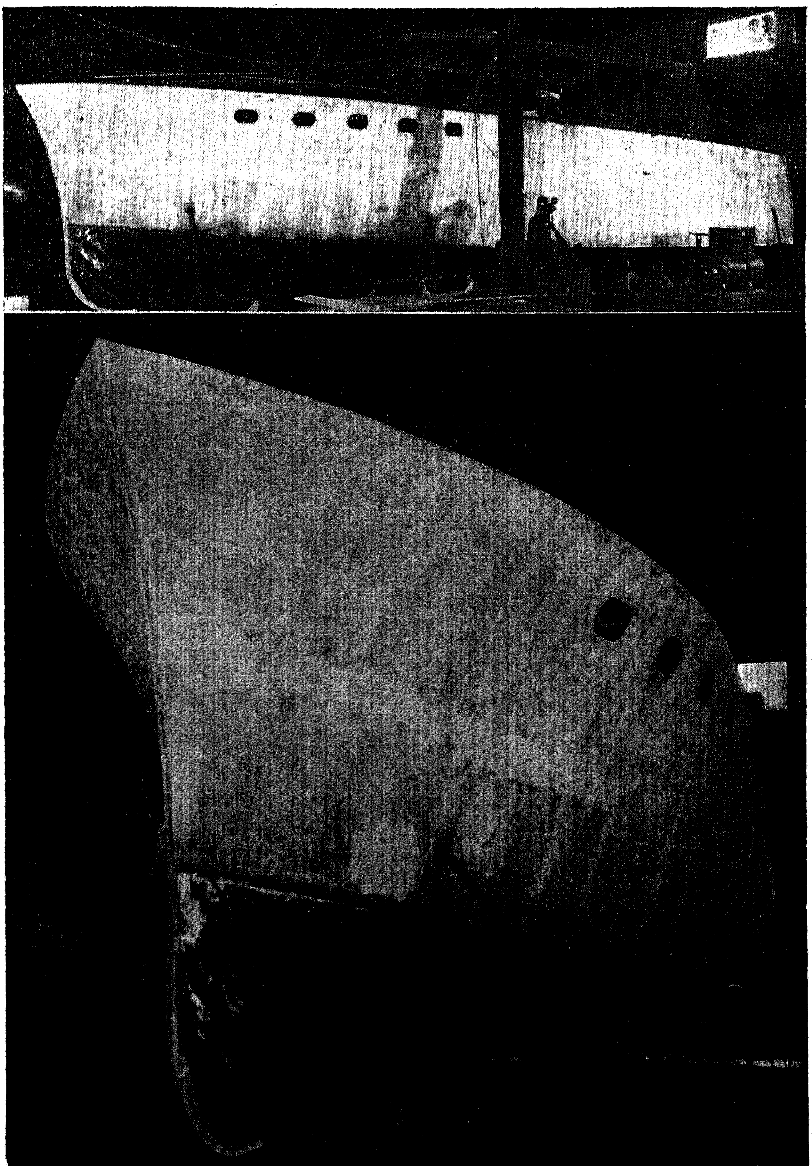


Fig. 1551. Welded steel cruiser 40 ft. long. Provides far greater service life, efficiency and economy than conventional wooden construction. It is permanently leakproof. Maintenance cost is one-fourth that of wood. Cabin insides cannot crack or open up. Hull can be frozen without harm. Provides complete insulation against heat, noise and vibration. Immune to marine borers. Quieter and simpler in operation. Eliminate caulking. It is lighter and far stronger.

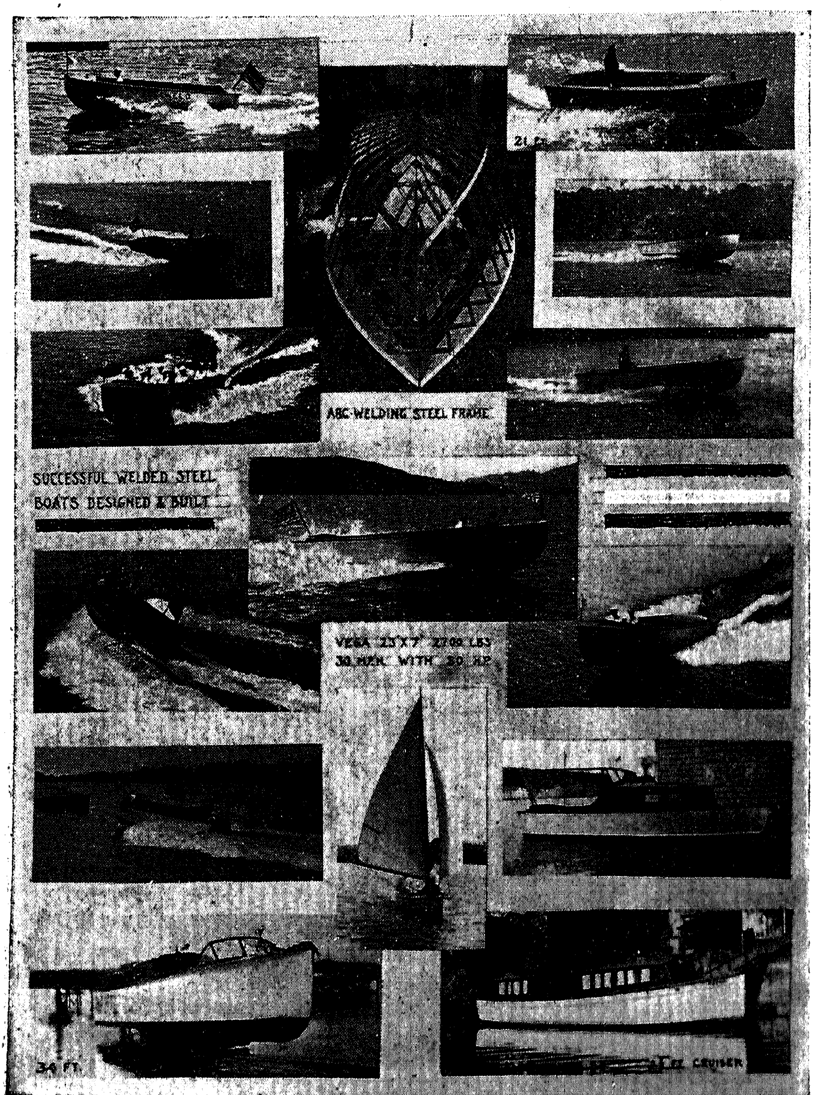


Fig. 1552. A number of pleasure boats of arc welded steel construction. This manufacturer claims the following advantages of welded steel over wooden construction for a typical boat: Top speed one mile per hour greater when new; three miles per hour greater after the wood is soaked; carrying capacity is 25% more. Cost of operation is 16% less. Cost of storage, refinishing and repairs is 50% less; cost of hull construction without motor was $200.00 less.

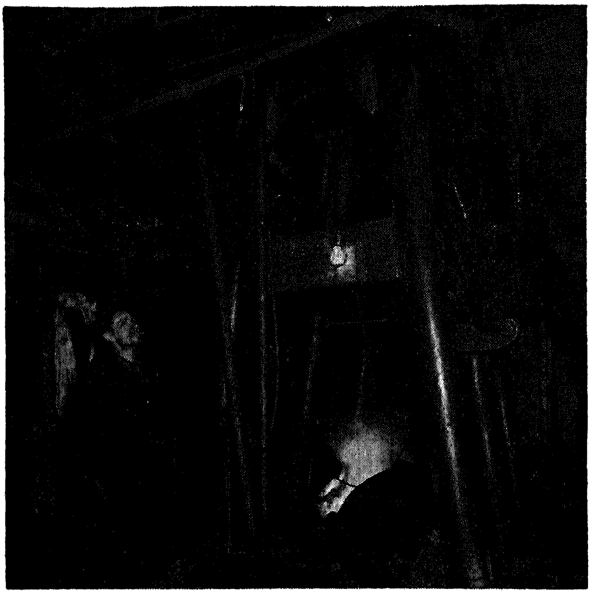


Fig. 1554. Cast iron columns of this vertical tug-boat engine were broken by a collision. The old columns were replaced with welded steel columns made from extra heavy pipe and 1-inch plate, saving $5,000 over replacement. The repair work was done during the winter season.

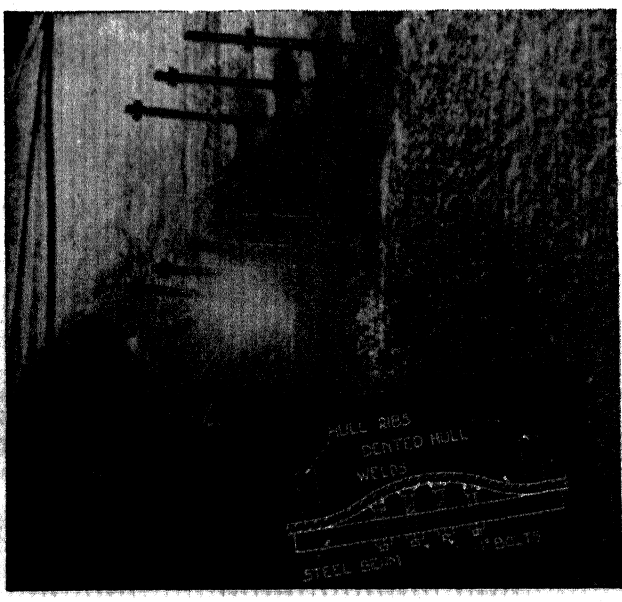


Fig. 1555. Repairing dent in freighter hull. 12 one-inch bolts (3 rows) were welded to hull and steel beams with holes were slipped over bolts as shown in inset. Dent was then pulled out by tightening nuts. Bolts were cut off with a torch.

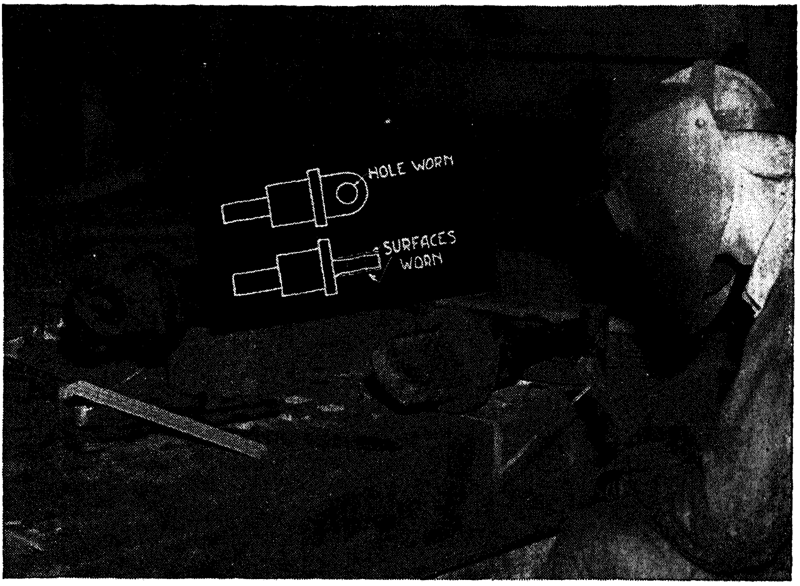


Fig. 1556. Repairing worn cargo pins. Head surfaces and hole were built up with mild steel electrode, then machined to original dimensions. Saved 50% of replacement cost.

Fig. 1557. Rebuilding cargo boom king post by welding the new flange as shown in inset. Flange was then welded to deck plate. Cut cost and time of riveted construction in half.

REFERENCE DATA

REFERENCE DATA

Weights and Measures

U. S. System

Length

12	inches	= 1	foot	ft.
3	feet	= 1	yard	yd.
5½	yards	= 1	rod	rd.
40	rods	= 1	furlong	fur.
8	furlongs	= 1	mile (statute)	mi.

Surveyor's Long Measure

25	links (l.)	= 1	rod	rd.
4	rods	= 1	chain	ch.
80	chains	= 1	mile (statute)	mi.
1.1527	statute miles	= 1	nautical mile	
3	nautical miles	= 1	league	

Area

144	square inches	= 1	square foot	sq. ft.
9	square feet	= 1	square yard	sq. yd.
30¼	square yards	= 1	square rod	sq. rd.
40	square rods	= 1	rood	
4	roods	= 1	acre	A.
640	acres	= 1	square mile	sq. mi.

Volume or Capacity

1728	cubic inches	= 1	cubic foot	cu. ft.
27	cubic feet	= 1	cubic yard	cu. yd.
128	cubic feet	= 1	cord of wood	cd.
24¾	cubic feet	= 1	perch of stone	pch.

Liquid Measure

4	gills	= 1	pint	pt.
2	pints	= 1	quart	qt.
4	quarts	= 1	gallon	gal.
31½	gallons	= 1	barrel	bbl.
2	barrels	= 1	hogshead	hhd.

Dry Measure

2	pints	= 1	quart	qt.
8	quarts	= 1	peck	pk.
4	pecks	= 1	bushel	bu.

Mass (Weight)—Troy

24	grains	= 1	pennyweight	pwt.
20	pennyweights	= 1	ounce	oz.
12	ounces	= 1	pound	lb.

Avoirdupois

16 ounces	= 1 pound	lb.
100 pounds	= 1 hundredweight	cwt.
20 hundredweight	= 1 ton	T.

Long Ton

16 ounces	= 1 pound	lb.
28 pounds	= 1 quarter	qr.
4 quarters	= 1 hundredweight	cwt.
20 hundredweight or 2240 pounds	= 1 long ton	T.

Metric System

Length

10 millimeters mm.	= 1 centimeter	cm.
10 centimeters	= 1 decimeter	dm.
10 decimeters	= 1 meter	m.
10 meters	= 1 dekameter	dkm.
10 dekameters	= 1 hectometer	hm.
10 hecktometers	= 1 kilometer	km.

Area

100 sq. millimeters mm^2	= 1 sq. centimeter	cm^2
100 sq. centimeters	= 1 sq. decimeter	dm^2
100 sq. decimeters	= 1 sq. meter or centare	m^2
100 sq. meters or centares	= 1 are	a
100 ares	= 1 hectare	ha
100 hectares	= 1 sq. kilometer	km^2

Volume or Capacity

10 milliliters	= 1 centiliter	cl.
10 centiliters	= 1 deciliter	dl.
10 deciliters	= 1 liter (1 cu.decimeter)	l.
10 liters	= 1 dekaliter	dkl.
10 dekaliters	= 1 hectoliter	hl.
10 hectoliters	= 1 kiloliter	kl.

Mass (Weight)

10 milligrams mg.	= 1 centigram	cg.
10 centigrams	= 1 decigram	dg.
10 decigrams	= 1 gram	g.
10 grams	= 1 dekagram	dkg.
10 dekagrams	= 1 hectogram	hg.
10 hectograms	= 1 kilogram	kg.
1000 kilograms	= 1 metric ton	t.

Metric Conversion Factors

Km. × .621 = mi.
Km. ÷ 1.609 = mi.
m. × 39.37 = in.
m. × 3.281 = ft.
m. × 1.094 = yd.
cm. × 3937 = in.
cm. ÷ 2.54 = in.
mm. × .03937 = in.
mm. ÷ 25.4 = in.
sq. km. × 247.1 = A.
sq. m. × 10.764 = sq. ft.
sq. cm. × .155 = sq. in.
sq. cm. ÷ 6.451 = sq. in.
sq. mm. × .00155 = sq. in.
sq. mm. ÷ 645.1 = sq. in.
cu. m. × 35.315 = cu. ft.
cu. m. × 1.308 = cu. yd.
cu. m. × 264.2 = gal. (U.S.)
cu. cm. ÷ 16.383 = cu. in.
l. × 61.022 = cu. in.
l. × .2642 = gal. (U.S.)
l. ÷ 3.78 = gal. (U.S.)
l. ÷ 28.316 = cu. ft.
g. × 15.432 = gr.
g. × 981 = dynes.
g. ÷ 28.35 = oz. (avoir.)
grams per sq. cm. × 14.22 = lb. per sq. in.
Kg. × 2.205 = lb.
Kg. × 35. = 3 oz. (avoir.)
Kg. × 1,102.3 = tons (2,000 lb.)
Kg. per sq. cm. × 14,233 = lb. per sq. in.
Kg.-m. × 7.233 = ft.-lb.
kilowatts (k. w.) × 1.34 = H. P.
watts ÷ 746 = H. P.
watts × .7373 = ft.-lb. per sec.
Joules × .7373 = ft.-lb.
Calorie (kilogram-degr. C.) × 3.968 = B. T. U.
Calorie (kilogram-degr. C.) ÷ .252 = B. T. U.
Joules × .24 = gram-calories
gram-calories × 4.19 = Joules
gravity (Paris) = 981 cm. per sec. per sec.
(Degrees Centigrade × 1.8) + 32° degrees F.

Decimals of An Inch for Each 1-64th

32nds	64ths	Decimal	Fraction	32nds	64ths	Decimal	Fraction	32nds	64ths	Decimal	Fraction
	1	.015625		11	22	.34375		22	44	.6875	11/16
1	2	.03125			23	.359375			45	.703125	
	3	.046875		12	24	.375	3/8	23	46	.71875	
2	4	.0625	1/16		25	.390625			47	.734375	
	5	.078125		13	26	.40625		24	48	.75	3/4
3	6	.09375			27	.421875			49	.765625	
	7	.109375		14	28	.4375	7/16	25	50	.78125	
4	8	.125	1/8		29	.453125			51	.796875	
	9	.140625		15	30	.46875		26	52	.8125	13/16
5	10	.15625			31	.484375			53	.828125	
	11	.171875		16	32	.5	1/2	27	54	.84375	
6	12	.1875	3/16		33	.515625			55	.859375	
	13	.203125		17	34	.53125		28	56	.875	7/8
7	14	.21875			35	.546875			57	.890625	
	15	.23475		18	36	.5625	9/16	29	58	.90625	
8	16	.25	1/4		37	.578125			59	.921875	
	17	.265625		19	38	.59375		30	60	.9375	15/16
9	18	.28125			39	.609375			61	.953125	
	19	.296875		20	40	.625	5/8	31	62	.96875	
10	20	.3125	5/16		41	.640625			63	.984375	
	21	.328125		21	42	.65625		32	64	1.	1
					43	.671875					

Weights of Alloys and Metals

Alloys and Metals	Lb. per cu. ft.	Lb. per cu. in.
Aluminum	163	0.0943
Aluminum and Tin:		
Al 91%, Sn 9%	178	0.103
Aluminum, Copper, and Tin:		
Al 85%, Cu 7.5%, Sn 7.5%	188	0.1087
Al 6.25%, Cu 87.5%, Sn 6.25%	459	0.2656
Al 5%, Cu 5%, Sn 90%	425	0.2459
Aluminum and Magnesium:		
Al 70%, Mg 30%	125	0.0723
Aluminum and Zinc:		
Al 91%, Zn 9%	175	0.1012
Antimony	419	0.2424
Babbitt Alloy	454	0.2627
Bismuth	611	0.3535
Bismuth, Lead, and Tin:		
Bi 53%, Pb 40%, Sn 7%	659	0.3813
Woods Metal:		
Bi 50%, Pb 25%, Cd 12.5%, Sn 12.5%	605	0.3501
Brass:		
Cu 90%, Zn 10%	536	0.3101
Cu 70%, Zn 30%	527	0.3049
Cu 60%, Zn 40%	521	0.3015
Cu 50%, Zn 50%	511	0.2957
Bronze:		
Cu 90%, Sn 10%	548	0.3171
Cu 85%, Sn 15%	555	0.3211
Cu 80%, Sn 20%	545	0.3153
Cu 75%, Sn 25%	551	0.3188
Cu 90%, Al 10%	480	0.2777
Cu 95%, Al 5%	522	0.3020
Cu 97%, Al 3%	542	0.3136
Bronze, Phosphorus, Average	537	0.3107
Bronze, Tobin, Average	503	0.291
Cadmium and Tin:		
Cd 32%, Sn 68%	480	0.2777
Chromium	436	0.2523
Cobalt	533	0.3084
Copper	557	0.3223
Copper and Nickel:		
Cu 60%, Ni 40%	554	0.3206
German Silver:		
Cu 60%, Zn 20%, Ni 20%	530	0.3067
Cu 52%, Zn 26%, Ni 22%	527	0.3049
Cu 59%, Zn 30%, Ni 11%	520	0.3009
Cu 63%, Zn 30%, Ni 7%	518	0.2997
Gold	1208	0.699
Gold and Copper:		
Au 98%, Cu 2%	1176	0.6805
Au 90%, Cu 10%	1071	0.6197
Au 86%, Cu 14%	1027	0.5943
Gun metal, Average	544	0.3148
Iridium	1396	0.8078
Iron, Cast	450	0.2604
Iron, Wrought	480	0.2777
Lead	708	0.4097

(Continued)

Weights of Alloys and Metals

Alloys and Metals	Lb. per cu. ft.	Lb. per cu. in.
Lead and Antimony:		
Pb 30%, Sb 70%	450	0.2604
Pb 37%, Sb 63%	460	0.2662
Pb 44%, Sb 56%	475	0.2748
Pb 63%, Sb 37%	514	0.2974
Pb 83%, Sb 17%	596	0.3449
Pb 90%, Sb 10%	658	0.3807
Lead and Bismuth:		
Bi 67%, Pb 33%	639	0.3697
Bi 50%, Pb 50%	656	0.3796
Bi 33%, Pb 67%	682	0.3946
Bi 25%, Pb 75%	697	0.4033
Bi 17%, Pb 83%	702	0.4062
Bi 12%, Pb 88%	703	0.4068
Lead and Tin:		
Pb 87.5%, Sn 12.5%	661	0.3825
Pb 84%, Sn 16%	644	0.3726
Pb 63.7%, Sn 36.3%	588	0.3402
Pb 46.7%, Sn 53.3%	545	0.3153
Pb 30.5%, Sn 69.5%	514	0.2974
Magnesium	109	0.063
Manganese	499	0.2887
Manganese, Copper, and Nickel:		
Mn 12%, Cu 84%, Ni 4%	530	0.3067
Mercury	849	0.4913
Nickel	550	0.3182
Osmium	1402	0.8113
Palladium	712	0.412
Platinum	1344	0.7777
Platinum and Iridium:		
Pt 90%, Iridium 10%	1348	0.780
Rhodium	755	0.4369
Ruthenium	765	0.4427
Silver	654	0.3784
Steel, Cast	490	0.2835
Tin	460	0.2662
Tin and Antimony:		
Sn 50%, Sb 50%	424	0.2453
Sn 75%, Sb 25%	442	0.2557
Tin and Bismuth:		
Bi 78%, Sn 22%	587	0.3396
Bi 63%, Sn 37%	570	0.3298
Bi 50%, Sn 50%	546	0.3159
Bi 37%, Sn 63%	530	0.3067
Bi 22%, Sn 78%	504	0.2916
Tin and Lead:		
Sn 97%, Pb 3%	456	0.2638
Sn 89%, Pb 11%	475	0.2748
Sn 80%, Pb 20%	487	0.2818
Sn 67%, Pb 33%	512	0.2962
Sn 50%, Pb 50%	550	0.3182
Titanium	224	0.1296
Tungsten	1078.7	0.6242
Zinc	437	0.2528

Physical Constants of Elements

Introduction—The following table has been compiled from the best available sources and checked by about fifty specialists on the various elements. While the data are believed to be accurate, certain generalizations have been necessary for tabulation and should, therefore, be used only for general purposes and comparison between elements. In general, the data are as published in the various sources from which they were selected.

The articles in this Handbook which deal with the individual elements should be consulted for more complete information, especially regarding minor variations and effect of special treatments on the properties listed.

Elements	Symbol	Atomic No.	Atomic Weight (1936)	Density, g./cm.^{3} at 20°C.	Density, lb./in.^{3} at 68°F	Melting Point, °F.	Boiling Point, °F.	Linear Coefficient of Thermal Expansion/°C. at Room Temperature	Linear Coefficient of Thermal Expansion/°F. at Room Temperature	Thermal Conductivity, cal./cm.^{2}/cm./°C./sec. at Room Temperature	Modulus of Elasticity (Tension), psi.
								$\times10^{-6}$	$\times10^{-6}$		10^6
Actinium	Ac	89	227			3272^d	>3092^d				
Aluminum	Al	13	26.97	2.70	0.0975	1220	3272	24	13.3	0.50	10
Antimony	Sb	51	121.76	6.620	0 2391	1166.9	2516	11.29	6.27	0.0444	11.3
Argon	A	18	39.944			−306.2	−301.5			0.406×10^{-4}	
Arsenic	As	33	74.91	5.73	0.2070	1497^d	1139^d	3.86	2.14		
Barium	Ba	56	137.36	3 5	0.1265	1562	2084				
Beryllium	Be	4	9.02	1.82	0.0658	2462	2732	12.3	6.8	0.3847	42.7
Bismuth	Bi	83	209.00	9.80	0.3541	519.8	2642	13.45	7.47	0.0200	4.6
Boron	B	5	10.82	2.3	0.0831	4172	4622	2	1.1		
Bromine	Br	35	79.916	3.119	0.1127	19.04	137.79				
Cadmium	Cd	48	112.41	8.648	0.3125	609.6	1403.6	29.8	16.6	0.217	
Calcium	Ca	20	40.08	1.55	0.0560	1564	2522	25	13.89		
Carbon	C	6	12.00	2.22	0.0802			1.5	0.8	0.039	1.19
Cerium	Ce	58	140.13	6.9	0 2493	1184	2552				
Cesium	Cs	55	132.91	1.9	0.0686	78.8	1238	97	54		
Chlorine	Cl	17	35.457			−150.88	−30.28	11.44	6.36	0.172×10^{-4}	
Chromium	Cr	24	52.01	7.138	0.2579	3326	3992	8.4	4.7	0.65	
Cobalt	Co	27	58.94	8.9	0.3216	2696	5252	12.08	6.71	0.165	
Columbium	Cb	41	92.91	8.57	0 3096	3542	>5972	7.2	4		
Copper	Cu	29	63.57	8.94	0.323	1981.4	4259	16.7	9.3	0.923	16
Dysprosium	Dy	66	162.46								
Erbium	Er	68	167.64								
Europium	Eu	63	152.0								
Fluorine	F	9	19.00			−369.4	−304.6				
Gadolinium	Gd	64	157.3								
Gallium	Ga	31	69.72	5.91	0.2135	85.6	>2900	18.3	10.2		
Germanium	Ge	32	72.60	5.36	0.1937	1757.3	4892				
Gold	Au	79	197.2	19.3	0.6973	1945.4	4712	14.4	8.0	0.7072	11.3
Hafnium	Hf	72	178.6	11.4	0.4118						
Helium	He	2	4.002	0.1785×10^{-3}	0.645×10^{-5}	>−458.0	−452.0			3.32×10^{-4}	
Holmium	Ho	67	163.5								
Hydrogen	H	1	1.0078	0.08987×10^{-3}	0.324×10^{-5}	−430.852	−422.957			4.06×10^{-4}	
Illinium	Il	61									
Indium	In	49	114.76	7.31	0.264	311	>2642	33	18.3	0.057	
Iodine	I	53	126.92	4.93	0.178	236.3	363.8	93	51.7	10.4×10^{-4}	
Iridium	Ir	77	193.1	22.4	0.809	4449	8670	6.7	3.7	0.14	
Iron	Fe	26	55.84	7.87	0.284	2795	5430	11.9	6.6	0.19	30
Krypton	Kr	36	83.7			−275.22	−250.6			0.212×10^{-4}	
Lanthanum	La	57	138.92	6.15	0.222	1518.8	3272				
Lead	Pb	82	207.22	11.35	0.409	621.2	2948	29.5	16.4	0.083	2.56
Lithium	Li	3	6.940	0.534	0.0193	366.8	2437	56	31	0.17	

Elements	Symbol	Atomic No.	Atomic Weight (1936)	Density, g./cm.^{3} at 20°C.	Density, lb./in.^{3} at 68°F.	Melting Point, °F.	Boiling Point, °F.	Linear Coefficient of Thermal Expansion/°C. at Room Temperature	Linear Coefficient of Thermal Expansion/°F. at Room Temperature	Thermal Conductivity, cal./cm.^{2}/cm./°C./sec. at Room Temperature	Modulus of Elasticity (Tension), psi.
								$\times 10^{-6}$	$\times 10^{-6}$		$\times 10^{6}$
Lutecium	Lu	71	175.0								
Magnesium	Mg	12	24.32	1.74	0.0628	1204	2007	25.7	14.3	0.37	6.25
Manganese	Mn	25	54.93	7.2	0.260	2273	3452	23	12.8		
Masurium	Ma	43									
Mercury	Hg	80	200.61	13.546	0.489	−38.0	674.4			0.0200	
Molybdenum	Mo	42	96.0	10.2	0.368	4748	6692	5.49	3.05	0.350	50.2
Neodymium	Nd	60	144.27	7.05	0.255	1544					
Neon	Ne	10	201.83	0.8999×10^{-3}	3.25×10^{-5}	−415.498	−411.34			1.092×10^{-4}	
Nickel	Ni	28	58.69	8.85	0.320	2645	5252	13.2	7.3	0.140	30
Nitrogen	N	7	14.008	1.2536×10^{-3}	4.525×10^{-5}	−346.216	−320.4652			0.580×10^{-4}	
Osmium	Os	76	191.5	22.48	0.812	4892	9570	6.1	3.4		
Oxygen	O	8	16.0000	1.42896×10^{-3}	5.159×10^{-5}	−361.12	−297.334			0.589×10^{-4}	
Palladium	Pd	46	106.7	12 0	0.433	2831	3992	12.0	6.6	0.161	
Phosphorus	P	15	31.02	1.82	0.0657	111.4	536	125	69		
Platinum	Pt	78	195.23	21.45	0.774	3224	7772	9.1	5.1	0.166	23.8
Polonium	Po	84									
Potassium	K	19	39.096	0.86	0.031	144.1	1400	83	46	0.237	
Praseodymium	Pr	59	140.92	6.625	0.239	1724					
Protoactinium	Pa	91	231								
Radium	Ra	88	226.05	5.0	0.1808	1760	2084				$\times 10^{6}$
Radon (Niton)	Rn	86	222	4.40[c]	0.159	−95.8	−79.2				
Rhenium	Re	75	186.31	21.0	0.758	5432		a	b		
Rhodium	Rh	45	102.91	12.5	0.452	3551	>4532	8.4	4.7	0.210	
Rubidium	Rb	37	85.44	1.53	0.0553	101	1292	90.0	50.0		
Ruthenium	Ru	44	101.7	12.2	0.441	4442	>4892	9.1	5.1		
Samarium	Sm	62	150.43	7.7	0.28	2400					
Scandium	Sc	21	45.10	2.5	0.09	2192	4352				
Selenium	Se	34	78.96	4.81	0.174	428	1270	37.0	20.6		
Silicon	Si	14	28.06	2.4	0.087	2588	4712	2.8–7.3	1.6–4.1	0.20	16
Silver	Ag	47	107.880	10.5	0.38	1761	3542	18.9	10.5	0.974	10.3
Sodium	Na	11	22.997	0.97	0.035	207.5	1616	71	39.5	0.3225	
Strontium	Sr	38	87.63	2.6	0.094	1472	2102				
Sulphur	S	16	32.06	2.07	0.075	235.4	832.3	67.48	37.49	0.00063	
Tantalum	Ta	73	180.88	16.6	0.60	5162	>7412	6.5	3.6	0.130	27.0
Tellurium	Te	52	127.61	6.24	0.224	846	2534	16.8	9.3	0.01433	
Terbium	Tb	65	159.2								
Thallium	Tl	81	204.39	11.85	0.428	578	3002	28.0	15.6	0.09315	
Thorium	Th	90	232.12	11.3–11.7	0.409–0.422	3353	>5432	12.3	6.84		
Thulium	Tm	69	169.4								
Tin	Sn	50	118.70	7.30	0.264	449.6	4100	20.0	11.12	0.157	5.9–7.8
Titanium	Ti	22	47.90	4.5	0.163	3272	>5432	7.14	3.96		
Tungsten	W	74	184.0	19.3	0.698	6098	10652	4.0	2.2	0.476	60
Uranium	U	92	238.14	18.7	0.676	3074	6332				
Vanadium	V	23	50.95	5.68	0.205	3110	5432				
Xenon	Xe	54	131.3			−169.6	−160.78			1.24×10^{-4}	
Ytterbium	Yb	70	173.04								
Yttrium	Y	39	88.92	5.51	0.199	2714	4532				
Zinc	Zn	30	65.38	7.14	0.258	787.0	1661	33.0	18.3	0.268	12.4
Zirconium	Zr	40	91.22	6.4	0.23	3092	>5252	6.3	3.5		

[c] Liquid at −62° C. [d] Sublimes. [a] 12.5 ± 8% ∥ crystal axis, 4.7 ± 8% ⊥ crystal axis. [b] 6.94 ± 8% ∥ crystal axis, 2.61 ± 8% ⊥ crystal axis.

Load Conversion Table for Testing

Tons per Sq. In. to Psi.						Kg. Per Sq. Mm. to Psi.					
Tons Per Sq. In.	Psi.	Tons Per Sq. In.	Psi.	Tons Per Sq. In.	Psi.	Kg. Per Sq. Mm.	Psi.	Kg. Per Sq. Mm.	Psi.	Kg. Per Sq. Mm.	Psi.
10.0	22,400	35.0	78,400	70	156,800	10	14,223	60	85,340	110	156,457
10.5	23,520	35.5	79,520	71	159,040	11	15,646	61	86,763	111	157,880
11.0	24,640	36.0	80,640	72	161,280	12	17,068	62	88,185	112	159,302
11.5	25,760	36.5	81,760	73	163,520	13	18,490	63	89,607	113	160,724
12.0	26,880	37.0	82,880	74	165,760	14	19,913	64	91,030	114	162,147
12.5	28,000	37.5	84,000	75	168,000	15	21,335	65	92,452	115	163,569
13.0	29,120	38.0	85,120	76	170,240	16	22,757	66	93,874	116	164,991
13.5	30,240	38.5	86,240	77	172,480	17	24,180	67	95,297	117	166,414
14.0	31,360	39.0	87,360	78	174,720	18	25,602	68	96,719	118	167,836
14.5	32,480	39.5	88,480	79	176,960	19	27,024	69	98,141	119	169,258
15.0	33,600	40.0	89,600	80	179,200	20	28,447	70	99,564	120	170,681
15.5	34,720	40.5	90,720	81	181,440	21	29,869	71	100,986	121	172,103
16.0	35,840	41.0	91,840	82	183,680	22	31,291	72	102,408	122	173,525
16.5	36,960	41.5	92,960	83	185,920	23	32,714	73	103,831	123	174,948
17.0	38,080	42.0	94,080	84	188,160	24	34,136	74	105,253	124	176,370
17.5	39,200	42.5	95,200	85	190,400	25	35,558	75	106,675	125	177,792
18.0	40,320	43.0	96,320	86	192,640	26	36,981	76	108,098	126	179,215
18.5	41,440	43.5	97,440	87	194,880	27	38,403	77	109,520	127	180,637
19.0	42,560	44.0	98,560	88	197,120	28	39,826	78	110,943	128	182,059
19.5	43,680	44.5	99,680	89	199,360	29	41,248	79	112,365	129	183,482
20.0	44,800	45.0	100,800	90	201,600	30	42,670	80	113,787	130	184,904
20.5	45,920	45.5	101,920	91	203,840	31	44,093	81	115,210	131	186,327
21.0	47,040	46.0	103,040	92	206,080	32	45,515	82	116,632	132	187,749
21.5	48,160	46.5	104,160	93	208,320	33	46,937	83	118,054	133	189,171
22.0	49,280	47.0	105,280	94	210,560	34	48,360	84	119,477	134	190,594
22.5	50,400	47.5	106,400	95	212,800	35	49,782	85	120,899	135	192,016
23.0	51,520	48.0	107,520	96	215,040	36	51,204	86	122,321	136	193,438
23.5	52,640	48.5	108,640	97	217,280	37	52,627	87	123,744	137	194,861
24.0	53,760	49.0	109,760	98	219,520	38	54,049	88	125,166	138	196,283
24.5	54,880	49.5	110,880	99	221,760	39	55,471	89	126,588	139	197,705
25.0	56,000	50	112,000	100	224,000	40	56,894	90	128,011	140	199,128
25.5	57,120	51	114,240	101	226,240	41	58,316	91	129,433	141	200,550
26.0	58,240	52	116,480	102	228,480	42	59,738	92	130,855	142	201,972
26.5	59,360	53	118,720	103	230,720	43	61,161	93	132,278	143	203,395
27.0	60,480	54	120,960	104	232,960	44	62,583	94	133,700	144	204,817
27.5	61,600	55	123,200	105	235,200	45	64,005	95	135,122	145	206,239
28.0	62,720	56	125,440	106	237,440	46	65,428	96	136,545	146	207,662
28.5	63,840	57	127,680	107	239,680	47	66,850	97	137,967	147	209,084
29.0	64,960	58	129,920	108	241,920	48	68,272	98	139,389	148	210,506
29.5	66,080	59	132,160	109	244,160	49	69,695	99	140,812	149	211,929
30.0	67,200	60	134,400	110	246,400	50	71,117	100	142,234	150	213,351
30.5	68,320	61	136,640	111	248,640	51	72,539	101	143,656	151	214,773
31.0	69,440	62	138,880	112	250,880	52	73,962	102	145,079	152	216,196
31.5	70,560	63	141,120	113	253,120	53	75,384	103	146,501	153	217,618
32.0	71,680	64	143,360	114	255,360	54	76,806	104	147,923	154	219,040
32.5	72,800	65	145,600	115	257,600	55	78,229	105	149,346	155	220,463
33.0	73,920	66	147,840	116	259,840	56	79,651	106	150,768	156	221,885
33.5	75,040	67	150,080	117	262,080	57	81,073	107	152,190	157	223,307
34.0	76,160	68	152,320	118	264,320	58	82,496	108	153,613	158	224,730
34.5	77,280	69	154,560	119	266,560	59	83,918	109	155,035	159	226,152

Temperature Conversion Table

C°	0	10	20	30	40	50	60	70	80	90
	F	F	F	F	F	F	F	F	F	F
-200	-328	-346	-364	-382	-400	-418	-436	-454	-----	-----
-100	-148	-166	-184	-202	-220	-238	-256	-274	-292	-310
-0	+32	+14	-4	-22	-40	-58	-76	-94	-112	-130
0	32	50	68	86	104	122	140	158	176	194
100	212	230	248	266	284	302	320	338	356	374
200	392	410	428	446	464	482	500	518	536	554
300	572	590	608	626	644	662	680	698	716	734
400	752	770	788	806	824	842	860	878	896	914
500	932	950	968	986	1004	1022	1040	1058	1076	1094
600	1112	1130	1148	1166	1184	1202	1220	1238	1256	1274
700	1292	1310	1328	1346	1364	1382	1400	1418	1436	1454
800	1472	1490	1508	1526	1544	1562	1580	1598	1616	1634
900	1652	1670	1688	1706	1724	1742	1760	1778	1796	1814
1000	1832	1850	1868	1886	1904	1922	1940	1958	1976	1994
1100	2012	2030	2048	2066	2084	2102	2120	2138	2156	2174
1200	2192	2210	2228	2246	2264	2282	2300	2318	2336	2354
1300	2372	2390	2408	2426	2444	2462	2480	2498	2516	2534
1400	2552	2570	2588	2606	2624	2642	2660	2678	2696	2714
1500	2732	2750	2768	2786	2804	2822	2840	2858	2876	2894
1600	2912	2930	2948	2966	2984	3002	3020	3038	3056	3074
1700	3092	3110	3128	3146	3164	3182	3200	3218	3236	3254
1800	3272	3290	3308	3326	3344	3362	3380	3398	3416	3434
1900	3452	3470	3488	3506	3524	3542	3560	3578	3596	3614
2000	3632	3650	3668	3686	3704	3722	3740	3758	3776	3794
2100	3812	3830	3848	3866	3884	3902	3920	3938	3956	3974
2200	3992	4010	4028	4046	4064	4082	4100	4118	4136	4154
2300	4172	4190	4208	4226	4244	4262	4280	4298	4316	4334
2400	4352	4370	4388	4406	4424	4442	4460	4478	4496	4514
2500	4532	4550	4568	4586	4604	4622	4640	4658	4676	4694
2600	4712	4730	4748	4766	4784	4802	4820	4838	4856	4874
2700	4892	4910	4928	4946	4964	4982	5000	5018	5036	5054
2800	5072	5090	5108	5126	5144	5162	5180	5198	5216	5234
2900	5252	5270	5288	5306	5324	5342	5360	5378	5396	5414
3000	5432	5450	5468	5486	5504	5522	5540	5558	5576	5594
3100	5612	5630	5648	5666	5684	5702	5720	5738	5756	5774
3200	5792	5810	5828	5846	5864	5882	5900	5918	5936	5954
3300	5972	5990	6008	6026	6044	6062	6080	6098	6116	6134
3400	6152	6170	6188	6206	6224	6242	6260	6278	6296	6314
3500	6332	6350	6368	6386	6404	6422	6440	6458	6476	6494
3600	6512	6530	6548	6566	6584	6602	6620	6638	6656	6674
3700	6692	6710	6728	6746	6764	6782	6800	6818	6836	6854
3800	6872	6890	6908	6926	6944	6962	6980	6998	7016	7034
3900	7052	7070	7088	7106	7124	7142	7160	7178	7196	7214
C°	0	10	20	30	40	50	60	70	80	90

Interpolation Columns

C°	F°
1	1.8
2	3.6
3	5.4
4	7.2
5	9.0
6	10.8
7	12.6
8	14.4
9	16.2
10	18.0

F°	C°
1	0.56
2	1.11
3	1.67
4	2.22
5	2.78
6	3.33
7	3.89
8	4.44
9	5.00
10	5.56
11	6.11
12	6.67
13	7.22
14	7.78
15	8.33
16	8.89
17	9.44
18	10.00

Weights of Steel Bars (Tables on Pages 1101-1103)

Carbon Steels—Approximate weights of carbon steel bars in rounds, squares, hexagons, octagons, and flats are given in the following tables. The weights given have been calculated from the unit, 1 cu. in. equals 0.2833 lb. or its equivalent, 1 cu. ft. equals 489.54 lb. A convenient unit much used in practice is 1 cu. in. equals 0.3 lb. This gives weights about 6% heavier than those in the tables, but since bar steel is usually furnished slightly full to size, weights calculated on this basis yield fairly close working results for all except very large sizes.

High Speed Steels—On account of the large proportion of special elements present, high speed steels are heavier than carbon steels. While this increased weight is not constant, a fairly close estimation of the weight of high speed steels may be obtained by adding 10% to the figures for carbon steels as given

(Continued)

Comparative Table of Wire Gages in Common Use in the U. S.

Dimensions of Sizes in Decimal Parts of an Inch

No. of Wire Gage	American or B. & S.	Birmingham or Stubs' Iron Wire	Washburn & Moen, Worcester, Mass.	W. & M. Steel Music Wire	New Am. S. & W. Co.'s Music Wire Gage	Imperial Wire Gage	Stubs' Steel Wire	U. S. Standard Gage for Sheet and Plate Iron and Steel	No. of Wire Gage
00000000	....	....	....	0.0083	....	....	....	....	00000000
0000000	....	....	0.490	0.0087	....	....	....	....	0000000
000000	....	....	0.4615	0.0095	0.004	0.464	....	0.46875	000000
00000	....	....	0.4305	0.010	0.005	0.432	....	0.4375	00000
0000	0.460	0.454	0.3938	0.011	0.006	0.400	....	0.40625	0000
000	0.40964	0.425	0.3625	0.012	0.007	0.372	....	0.375	000
00	0.3648	0.380	0.3310	0.0133	0.008	0.348	....	0.34375	00
0	0.32486	0.340	0.3065	0.0144	0.009	0.324	....	0.3125	0
1	0.2893	0.300	0.2830	0.0156	0.010	0.300	0.227	0.28125	1
2	0.25763	0.284	0.2625	0.0166	0.011	0.276	0.219	0.265625	2
3	0.22942	0.259	0.2437	0 0178	0.012	0.252	0.212	0.250	3
4	0.20431	0.238	0.2253	0.0188	0.013	0 232	0.207	0.234375	4
5	0.18194	0.220	0.2070	0.0202	0.014	0.212	0.204	0.21875	5
6	0.16202	0.203	0.1920	0.0215	0.016	0.192	0.201	0.203125	6
7	0.14428	0.180	0.1770	0.023	0.018	0.176	0.199	0.1875	7
8	0.12849	0.165	0.1620	0.0243	0.020	0.160	0.197	0.171875	8
9	0.11443	0.148	0.1483	0.0256	0.022	0.144	0.194	0.15625	9
10	0.10189	0.134	0.1350	0.027	0.024	0.128	0.191	0.140625	10
11	0.090742	0.120	0.1205	0.0284	0.026	0.116	0.188	0.125	11
12	0.080808	0.109	0.1055	0.0296	0.029	0.104	0.185	0.109375	12
13	0.071961	0.095	0.0915	0.0314	0.031	0.092	0.182	0.09375	13
14	0.064804	0.083	0.0800	0.0326	0.033	0.080	0.180	0.078125	14
15	0.057068	0.072	0.0720	0.0345	0.035	0.072	0.178	0.0703125	15
16	0.05082	0 065	0.0625	0.036	0.037	0.064	0.175	0.0625	16
17	0.045257	0.058	0.0540	0.0377	0.039	0.056	0.172	0.05625	17
18	0.040303	0.049	0.0475	0.0395	0.041	0.048	0.168	0.050	18
19	0.03589	0.042	0.0410	0.0414	0.043	0.040	0.164	0.04375	19
20	0.031961	0.035	0.0348	0.0434	0.045	0.036	0.161	0.0375	20
21	0.028462	0.032	0.03175	0.046	0.047	0.032	0.157	0.034375	21
22	0.025347	0.028	0.0286	0.0483	0.049	0.028	0.155	0.03125	22
23	0.022571	0.025	0.0258	0 051	0.051	0.024	0.153	0.028125	23
24	0.0201	0.022	0.0230	0.055	0.055	0.022	0.151	0.025	24
25	0.0179	0.020	0.0204	0.0586	0.059	0.020	0.148	0.021875	25
26	0.01594	0.018	0 0181	0.0626	0.063	0.018	0.146	0.01875	26
27	0.014195	0.016	0.0173	0 0658	0.067	0.0164	0.143	0.0171875	27
28	0.012641	0 014	0.0162	0.072	0.071	0.0149	0.139	0.015625	28
29	0.011257	0.013	0.0150	0.076	0.075	0.0136	0.134	0.0140625	29
30	0.010025	0.012	0.0140	0.080	0.080	0.0124	0.127	0.0125	30
31	0.008928	0.010	0.0132	....	0.085	0.0116	0.120	0.0109375	31
32	0.00795	0.009	0.0128	....	0.090	0.0108	0.115	0.01015625	32
33	0.00708	0.008	0.0118	....	0.095	0.0100	0.112	0.009375	33
34	0.006304	0.007	0.0104	....	....	0.0092	0.110	0.00859375	34
35	0.005614	0.005	0.0095	....	....	0.0084	0.108	0.0078125	35
36	0.005	0.004	0.0090	....	....	0.0076	0.106	0.00703125	36
37	0.004453	....	....	....	....	0.0068	0.103	0.006640625	37
38	0.003965	....	....	....	....	0.0060	0.101	0.00625	38
39	0.003531	....	....	....	....	0.0052	0.099	....	39
40	0.003144	....	....	....	....	0.0048	0.097	....	40

Weights of Steel Bars—Continued

in the tables. In other words, multiply the figures in the tables by 1.1 to obtain the weight of high speed steel.

Useful Methods for Calculating Weights—There are several methods which may often be used to advantage in determining weights of odd-sized bars not included in the subsequent tables.

(1) To find the weight per ft. of any size round, square or octagon, square the diameter (or stated dimension) and multiply by the weight per ft. of 1 in. round, square or octagon, respectively.

(2) The weight per ft. of octagon steel may be found by multiplying the weight per ft. of a round bar of the same size by 1.0547.

(3) The weight per ft. of hexagon steel may be found by multiplying the weight per ft. of a round bar of the same size by 1.1026.

(4) To find the weight per ft. of any flat, multiply the product of the width and thickness by the weight per ft. of 1 in. sq.

Weights and Areas of Carbon Steel Bars

Weight per Lineal Ft. and per In. in Lb.

Size, Round or Square, In.	ROUND BARS Area, Sq. In.	ROUND BARS Weight, Per In.	ROUND BARS Weight, Per Ft.	SQUARE BARS Area, Sq. In.	SQUARE BARS Weight, Per In.	SQUARE BARS Weight, Per Ft.	OCTAGON BARS Weight, Per Ft.	OCTAGON BARS Weight, Per In.	HEXAGON BARS Weight, Per Ft.	HEXAGON BARS Weight, Per In.
1/16	0.0031	0.00087	0.010	0.0039	0.001083	0.013	0.011	0.000917	—	—
1/8	0.0123	0.0035	0.042	0.0156	0.00441	0.053	0.044	0.00367	0.046	0.00383
3/16	0.0276	0.00783	0.094	0.0352	0.00991	0.119	0.099	0.00825	0.10	0.00833
1/4	0.0491	0.0139	0.167	0.0625	0.01766	0.212	0.176	0.0147	0.18	0.015
5/16	0.0767	0.0217	0.261	0.0977	0.0278	0.333	0.276	0.023	0.29	0.0242
3/8	0.1105	0.0312	0.375	0.1406	0.0398	0.478	0.397	0.033	0 41	0.0342
7/16	0.1503	0.0425	0.511	0.1914	0.0543	0.651	0.540	0.045	0.56	0.0466
1/2	0.1964	0.0555	0.667	0.25	0.0708	0.850	0.706	0.0588	0.74	0.0616
9/16	0.2485	0.0704	0.845	0.3164	0.0897	1.076	0.893	0.0744	0.93	0.0775
5/8	0.3068	0.0867	1.043	0.3906	0.1106	1.328	1.102	0 09183	1.15	0.0958
11/16	0.3712	0.105	1.262	0.4727	0.134	1.608	1.325	0.1104	1.40	0.1166
3/4	0.4418	0.125	1.502	0.5625	0.1594	1.913	1.588	0.1323	1.66	0.1383
13/16	0.5185	0.1469	1.763	0.6602	0.187	2.245	1.863	0.1552	1.94	0.1617
7/8	0.6013	0.1703	2.044	0.7656	0.217	2.603	2.161	0.1801	2.25	0.1875
15/16	0.6903	0.1955	2.347	0.8789	0.249	2.989	2.481	0.2067	2.59	0.2158
1	0.7854	0.2225	2.670	1.000	0.283	3.400	2.822	0.2351	2.94	0.245
1/16	0.8866	0.2511	3.014	1.1289	0.320	3.838	3.186	0.2655	3.32	0.2766
1/8	0.9940	0.2815	3.379	1.2656	0.3585	4.303	3.572	0 2976	3.73	0.3108
3/16	1.1075	0.3138	3.766	1.41	0.3996	4.795	3.980	0.3316	4.15	0.3458
1/4	1.2272	0.3477	4.173	1.56	0.4427	5.312	4.409	0.3674	4.60	0.3833
5/16	1.3530	0.3833	4.600	1.72	0.488	5.857	4.861	0.405	5.06	0.4216
3/8	1.4849	0.4207	5.049	1.89	0.5357	6.428	5.335	0.4445	5.54	0.4616
7/16	1.6230	0.4598	5.518	2.07	0.5855	7.026	5.832	0.486	6.06	0.505
1/2	1.7671	0.5007	6.008	2.25	0.6375	7.650	6.350	0.529	6 63	0.5525
9/16	1.9175	0.5433	6.520	2.44	0.6917	8.301	6.890	0.5741	7.17	0.5975
5/8	2.0739	0.5875	7.051	2.64	0.748	8.978	7.452	0.621	7.78	0.6483
11/16	2.2365	0.6336	7.604	2.85	0.8068	9.682	8.036	0 6696	8 37	0.6975
3/4	2.4053	0.6815	8.178	3.06	0.8675	10.41	8.640	0.72	9.02	0.7514
13/16	2.5802	0.731	8.773	3.29	0.9308	11.17	9.271	0.7725	9.67	0.8058
7/8	2.7612	0.782	9.388	3.52	0.9958	11.95	9.919	0.8265	10.36	0.8633
15/16	2.9483	0.835	10.02	3.75	1.063	12.76	10.59	0.899	11.05	0.92
2	3.1416	0.89	10.68	4.00	1.133	13.60	11.29	0.9408	11.78	0.9817
1/16	3.3410	0.947	11.36	4.25	1.205	14.46	12.00	1.0	12.51	1.1042
1/8	3.5466	1.005	12.06	4.52	1.279	15.35	12.74	1.062	13.30	1.108
3/16	3.7583	1.065	12.78	4.79	1.355	16.27	13.50	1.125	14.08	1.173
1/4	3.9761	1.126	13.52	5.06	1.435	17.22	14.29	1.1908	14.91	1.243
5/16	4.200	1.19	14.28	5.35	1.515	18.19	15.10	1.2583	15 74	1.312
3/8	4.4301	1.255	15.07	5.64	1.598	19.18	15.92	1.3266	16.62	1.383
7/16	4.6664	1.32	15.86	5.94	1.683	20.20	16.77	1.3975	17.50	1.458
1/2	4.9087	1.39	16.69	6.25	1.771	21.25	17.64	1.47	18.41	1.534
9/16	5.1572	1.46	17.53	6.47	1.861	22.33	18.53	1.5441	19.35	1.612
5/8	5.4119	1.533	18.40	6.89	1.952	23.43	19.45	1.62	20.30	1.691
11/16	5.6727	1.607	19.29	7.22	2.046	24.56	20.38	1.698	21.28	1.773

Weights and Areas of Carbon Steel Bars
Weight per Lineal Ft. and per In. in Lb.

Size, Round or Square, In.	ROUND BARS Area, Sq. In.	ROUND BARS Weight, Per In.	ROUND BARS Weight, Per Ft.	SQUARE BARS Area Sq. In.	SQUARE BARS Weight, Per In.	SQUARE BARS Weight, Per Ft.	OCTAGON BARS Weight, Per Ft.	OCTAGON BARS Weight, Per In.	HEXAGON BARS Weight, Per Ft.	HEXAGON BARS Weight, Per In.
¾	5.9396	1.683	20.20	7.56	2.083	25.00	20.75	1.729	22.28	1.857
13/16	6.2126	1.76	21.12	7.91	2.241	26.90	22.33	1.861	23.30	1.942
⅞	6.4918	1.84	22.07	8.27	2.341	28.10	23.32	1.943	24.34	2.03
15/16	6.7771	1.916	23.04	8 63	2.445	29.34	24.35	2.029	25.40	2.117
3	7.0686	2.00	24.03	9 00	2.55	30.60	25.40	2.117	26.51	2.209
1/16	7.3662	2.087	25.04	9.3789	2.658	31.89	26.47	2.205	27.89	2.324
⅛	7.6699	2.173	26.08	9.7656	2.766	33.20	27.56	2.296	28.77	2.397
3/16	7.9798	2.275	27.13	10.16	2.88	34.55	28.68	2.39	29.90	2.491
¼	8.2958	2.35	28.20	10.56	2.993	35.92	29.81	2.484	31.10	2.591
5/16	8.6179	2.441	29.30	10.97	3.11	37.31	30.97	2.58	32.29	2.69
⅜	8.9462	2.533	30.42	11.39	3.23	38.73	32.15	2.679	33.75	2.812
7/16	9.2806	2.63	31.56	11.82	3.348	40.18	33.35	2.78	34.75	2.895
½	9.6211	2.726	32.71	12.95	3.47	41.65	34.57	2.88	36.08	3.00
9/16	9.9678	2.825	33.90	12.695	3.595	43.14	35.81	2.983	37.34	3.11
⅝	10.321	2.92	35.09	13.14	3.723	44.68	37.08	3.09	38.70	3.225
11/16	10.680	3.026	36.31	13.60	3.853	46.24	38.38	3.20	40.00	3.333
¾	11.045	3.13	37.56	14.06	3.993	47.82	39.69	3.31	41.43	3.452
13/16	11.416	3.234	38.81	14.54	4.118	49.42	41.02	3.42	42.75	3.562
⅞	11.793	3.342	40.10	15.015	4.254	51.05	42.39	3.53	44.20	3.683
15/16	12.177	3.45	41.40	15.51	4.392	52.71	43.75	3.646	45.65	3.804
4	12.566	3.56	42.73	16.00	4.533	54.40	45.15	3.762	47.13	3.927
1/16	12.962	3.672	44.07	16.51	4.675	56.11	46.57	3.88		
⅛	13.364	3.783	45.44	17.02	4.895	58.75	48.02	4.00		
3/16	13,772	3.9	46.83	17.54	4.968	59.62	49.48	4.123		
¼	14.186	4.02	48.24	18.06	5.117	61.41	50.97	4.247	53.21	4.434
5/16	14.607	4.138	49.66	18.60	5.27	63.23	52.48	4.373		
⅜	15.033	4.259	51.11	19.14	5.42	65.08	54.02	4.5		
7/16	15.466	4.381	52.58	19.70	5.58	66.95	55.57	4.63		
½	15.904	4.505	54.07	20.25	5.737	68.85	57.15	4.762	59.64	4.97
9/16	16.349	4.632	55.59	20.82	5.898	70.78	58.75	4.895		
⅝	16.800	4.76	57.12	21.39	6.06	72.73	60.37	5.03		
11/16	17.257	4.89	58.67	21.98	6.225	74.70	62.00	5.166		
¾	17.721	5.02	60.25	22.56	6.392	76.71	63.67	5.305	66.46	5.538
13/16	18.190	5.153	61.84	23.164	6.562	78.74	65.35	5.446		
⅞	18.665	5.288	63.46	23.77	6.734	80.81	67.07	5.59		
15/16	19.147	5.416	65.10	24.38	6.907	82.89	68.80	5.733		
5	19.635	5.563	66.76	25.00	7.083	85.00	70.55	5.879	73.54	6.128
1/16	20.129	5.703	68.44	25.63	7.262	87.14	72.33	6.028		
⅛	20.629	5.845	70.14	26.27	7.441	89.30	74.12	6.176		
3/16	21.135	5.988	71.86	26.92	7.624	91.49	75.94	6.328		
¼	21.648	6.133	73.60	27.56	7.81	93.72	77.79	6.483	81.18	6.765
5/16	22.166	6.28	75.37	28.23	7.997	95.96	79.65	6.637		
⅜	22.691	6.43	77.15	28.89	8.185	98.23	81.53	6.794		

Weights and Areas of Carbon Steel Bars
Weight per Lineal Ft. and per In. in Lb.

Size, Round or Square, In.	ROUND BARS Area Sq. In.	ROUND BARS Weight, Per In.	ROUND BARS Weight Per Ft.	SQUARE BARS Area, Sq. In.	SQUARE BARS Weight, Per In.	SQUARE BARS Weight, Per Ft.	OCTAGON BARS Weight, Per Ft.	OCTAGON BARS Weight, Per In.	HEXAGON BARS Weight, Per Ft.	HEXAGON BARS Weight, Per In.
7/16	23.221	6.579	78.95	29.57	8.375	100.5	83.42	6.951		
1/2	23.758	6.73	80.77	30.25	8.566	102.8	85.32	7.11	89.09	7.424
9/16	24.301	6.885	82.62	30.95	8.77	105.2	87.31	7.275		
5/8	24.850	7.04	84.49	31.64	8.97	107.6	89.31	7.442		
11/16	25.406	7.198	86.38	32.35	9.17	110.0	91.30	7.608		
3/4	25.967	7.358	88.29	33.06	9.37	112.4	93.29	7.774	97.38	8.115
13/16	26.535	7.518	90.22	33.79	9.58	114.9	95.37	7.947		
7/8	27.109	7.68	92.17	34.52	9.783	117.4	97.44	8.12		
15/16	27.688	7.845	94.14	35.26	9.991	119.9	99.52	8.293		
6	28.274	8.01	96.14	36.00	10.2	122.4	101.6	8.466	106.04	8.836
1/16	28.50	8.178	98.14	36.76	10.416	125.0	103.8	8.65		
1/8	29.465	8.35	100.2	37.52	10.633	127.6	105.9	8.825		
3/16	30.06	8.51	102.2	38.29	10.85	130.2	108.1	9.00		
1/4	30.680	8.69	104.3	39.06	11.07	132.8	110.2	9.183		
5/16	31.29	8.875	106.4	39.85	11.3	135.5	112.47	9.372		
3/8	31.92	9.04	108.5	40.64	11.51	138.2	114.7	9.558		
7/16	32.55	9.225	110.7	41.45	11.74	140.9	116.9	9.742		
1/2	33.18	9.4	112.8	42.25	11.97	143.6	119.2	9.933	124.42	10.368
9/16	33.80	9.575	114.9	43.07	12.2	146.5	121.6	10.133		
5/8	34.49	9.766	117.2	43.89	12.43	149.2	123.8	10.316		
11/16	35.12	9.95	119.4	44.73	12.675	152.1	126.2	10.516		
3/4	35.78	10.14	121.7	45.56	12.99	154.9	128.6	10.716		
13/16	36.44	10.325	123.9	46.42	13.15	157.8	131.0	10.916		
7/8	37.13	10.51	126.2	47.27	13.4	160.8	133.5	11.125		
15/16	13.79	10.708	128.5	48.14	13.633	163.6	135.8	11.316		
7	38.48	10.908	130.9	49.00	13.883	166.6	138.3	11.525	144.38	12.031
1/16	39.18	11.1	133.2	49.89	14.13	169.6	140.8	11.733		
1/8	39.88	11.3	135.6	50.77	14.383	172.6	143.3	11.941		
3/16	40.59	11.5	137.9	51.67	14.633	175.6	145.7	12.141		
1/4	41.28	11.7	140.4	52.56	14.891	178.7	148.3	12.36		
5/16	42.00	11.9	142.8	53.48	15.15	181.8	150.8	12.57		
3/8	42.73	12.108	145.3	54.39	15.408	184.9	153.5	12.79		
7/16	43.45	12.308	147.7	55.32	15.675	188.1	156 1	13.00		
1/2	44.17	12.517	150.2	56.25	15.94	191.3	158.8	13.23		
5/8	45.68	12.85	155.2	58.14	16.475	197.7	164.2	13.68		
3/4	47.19	13.358	160.3	60.06	17.016	204.2	169.5	14.125		
7/8	48.73	13.8	165.6	62.33	17.566	210.8	175.0	14.58		
8	50.26	14.25	171.0	64.00	18.133	217.6	180.6	15.05	188.61	15.718
9	63.61	18.2	218.4	81.00	22.966	275.6	227.8	18.983	238.58	19.88
10	78.54	22.266	267.2	100.00	29.166	340.0	282.4	23.533	294.50	24.542
11	95.03	26.916	323.0	121.00	34.266	411.2	340 6	28.38	356.38	29.698
12	113.10	32.033	384.4	144.00	40.8	489.6	405.8	33.82	428.64	35.72

Interconversion Table for Units of Volume and Weight

Multiply by

To Convert From	To Cu.in.	To Cu.ft.	To Cu.yd.	To Fl.oz.	To Pt.	To Qt.	To Gal.	To Grain	To Oz.Troy	To Oz.Av.	To Lb.Troy	To Lb.Av.	To C.C. or G.	To L. or Kg.
Cu.in.	1.00000	$0.0_{3}5787$	$0.0_{4}2143$	0.554112	0 034632	0 017316	0 004329	252 891	0 526857	0 578037	0 043905	0.036127	16 3871	0 016387
Cu.ft.	1728.00	1.00000	0.037037	957.505	59 8442	29.9221	7.48052	436996	910.408	998 848	75 8674	62 4280	28316.9	28 3169
Cu.yd.	46656.0	27.0000	1.00000	25852 6	1615 79	807.896	201 974	117990_{8}	24581.0	26968 9	2048 42	1685 56	764556	764 556
Fl oz.	1.80469	0.001044	$0\ 0_{4}3868$	1.00000	0.062500	0 031250	0 007813	456 390	0 950813	1 04318	0 079234	0 065199	29 5736	0.029573
Pt.	28.8750	0 016710	$0.0_{3}6189$	16.0000	1 00000	0.500000	0.125000	7302 23	15 2130	16 6908	1 26775	1 04318	473.177	0 473177
Qt.	57.7500	0 033420	0.001238	32 0000	2 00000	1 00000	0.250000	1460 45	30 4260	33 3816	2 53550	2 08635	946 354	0 946354
Gal.	231.000	0.133681	0.004951	128 000	8 00000	4 00000	1.00000	58417.9	121 704	133 527	10 1420	8.34541	3785.42	3.78542
Grain	0.003954	$0.0_{5}2288$	$0.0_{7}8475$	0.002191	$0.0_{3}1369$	$0.0_{4}6850$	$0\ 0_{4}1712$	1 00000	0.002083	0 002286	$0\ 0_{3}1735$	$0.0_{3}1428$	0 064799	$0\ 0_{4}6479$
Oz. Troy	1.89805	0.001098	$0.0_{4}4068$	1.05173	0.065733	0.032867	0 008217	480 000	1.00000	1 09714	0 083333	0 068571	31 1035	0 031104
Oz. Av.	1.72999	0.001001	$0.0_{4}3708$	0.958608	0.059913	0 029957	0.007489	437 500	0 911457	1.00000	0 075955	0 062500	28 3495	0 028350
Lb. Troy	22.7766	0.013181	$0.0_{3}4882$	12.6208	0.788800	0 394400	0.098600	5760 00	12 0000	13 1657	1 00000	0 822857	373 242	0 373242
Lb. Av.	27.6799	0.016018	$0.0_{3}5933$	15 3378	0 958611	0.479306	0 119826	7000 00	14.5833	16 0000	1 21528	1.00000	453.593	0 453593
C.C. or G.	0.061024	$0.0_{4}3531$	$0.0_{5}1308$	0.033814	0.002113	0.001057	$0\ 0_{3}2642$	15 4323	0 032151	0 035274	0 002679	0 002205	1 00000	0 001000
L. or Kg.	61.0237	0.035315	0.001308	33.8140	2.11337	1.05669	0.264172	15432 3	32 1507	35 2739	2.67923	2 20462	1000.00	1 00000

Note: The small subnumeral following a zero indicates that the zero is to be taken that number of times, thus, $0\ 0_{3}1428$ is equivalent to 0.0001428

Values Used in Constructing Table: 1 in. = 2.540001 cm.; 1 cu. in. = 16.387083 C.C. = 16 387083 g. H_2O at 4°C = 39°F.; 1 lb. av. = 453 5926 g.; 1 gal. = 8.34541 lb.; 1 lb av. = 27 679886 cu. in. H_2O at 4°C.; 1 lb. av. = 7000 grains; 1 gal. = 58417.87 grains; 231 cu in. = 1 gal. = 3785.4162 g.

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Note: *(P)*-Procedures

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Note: *(P)*-Procedures

Note: *(P)*-Procedures

H

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Note: *(P)*-Procedures

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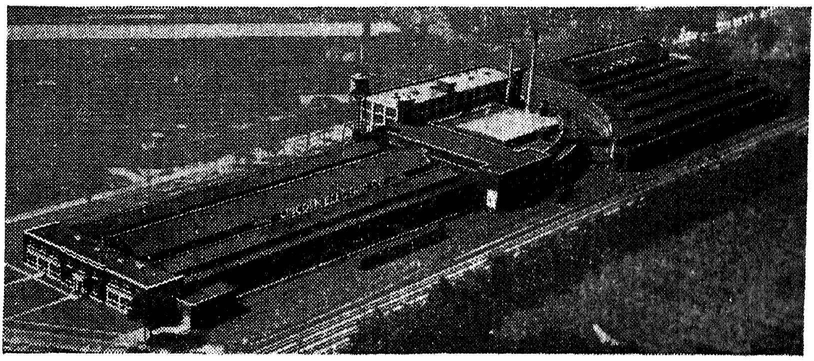
T

U

V

W

LINCOLN
ARC WELDING
PRODUCTS AND SERVICES

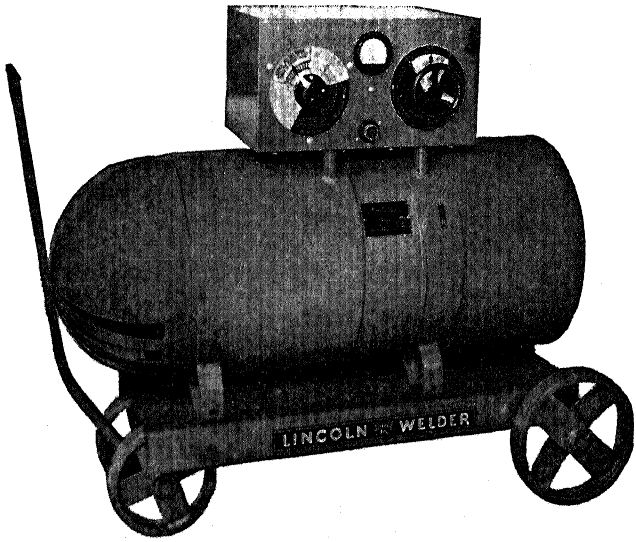


Main Offices and Factory of The Lincoln Electric Company, Cleveland, Ohio

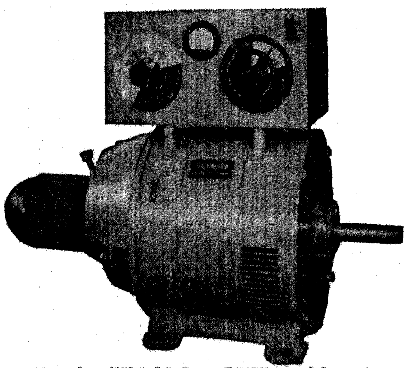
LINCOLN ARC WELDING PRODUCTS AND SERVICES

Introduction.—The Lincoln Electric Company has been engaged in the manufacture of arc welding equipment for more than a quarter of a century. For all these years this company has been, and still is, the largest manufacturer of arc welding equipment in the world. It is therefore only logical that users of the electric arc welding process refer to The Lincoln Electric Company as "Arc Welding Headquarters." Such world-wide recognition definitely proclaims Lincoln's leadership of the industry.

Lincoln Electric maintains this unique position in the industry by virtue of its progressive policy of constant search and research for ways and means to improve its products with resultant advancement

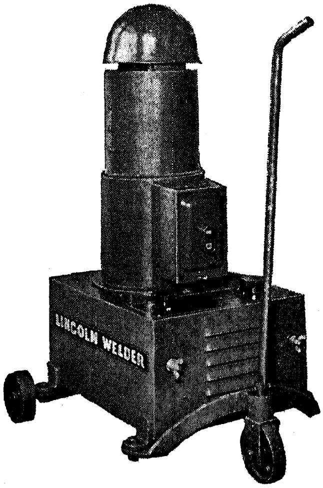


Lincoln "Shield-Arc SAE" welder, motor driven type, with self-indicating job selector and self-indicating current control. Both controls are continuous in operation.

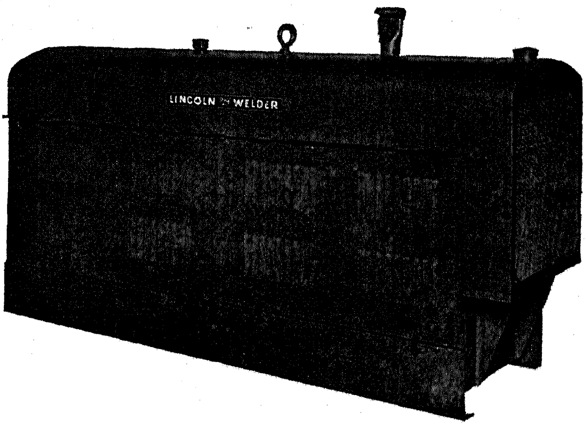


Lincoln "Shield-Arc SAE" welder, for belt or direct drive.

in the art of welding. Because it was the first to use arc welding in the manufacture of its own products . . . the first to sponsor the application of arc welding in practically all industries . . . the first to make available to industry all of the important improvements of the process . . . The Lincoln Electric Company possesses the most complete



Lincoln welder for sheet metal work and general repairs.



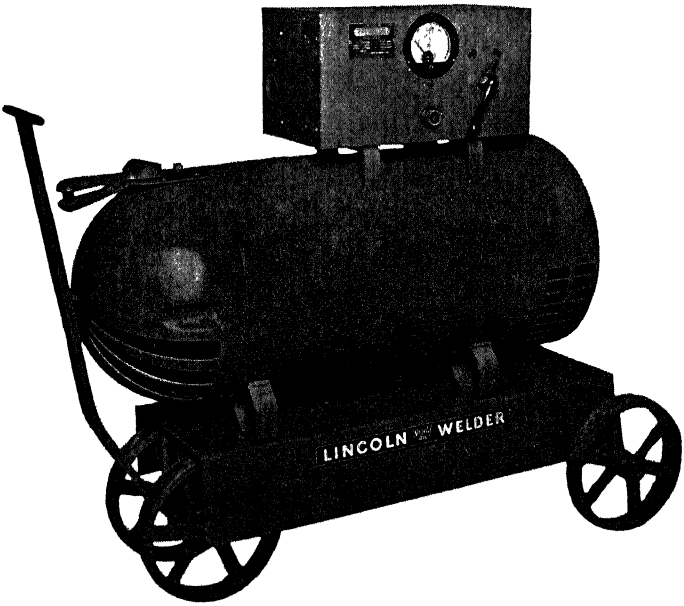
Lincoln welder, engine driven type.

knowledge of arc welding, and experience in its applications. The present design and construction of Lincoln welding equipment is the result of this vast fund of accumulated knowledge and experience.

Lincoln Welders.—The Lincoln Electric Company manufactures a complete line of arc welding machines for generation of welding current both a.c. and d.c. Lincoln welders are built in 75, 100, 150, 200, 300, 400 and 600 ampere sizes. Motor driven, Diesel or gasoline

engine driven and belt driven types are available. Descriptive bulletins will be furnished upon request.

Lincoln Automatic Welders.—For automatic welding, The Lincoln Electric Company manufactures the "Electronic Tornado" welding head which is furnished either separately or with travel carriage and



Lincoln "Shield-Arc A.C." welder, motor-generator type for A.C. welding.

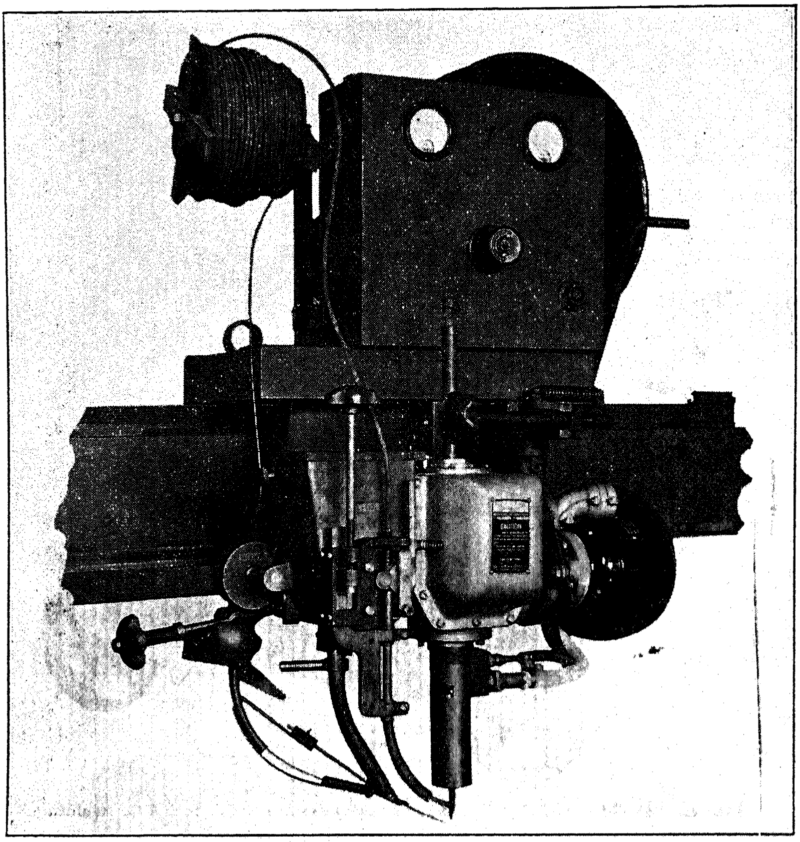
fixture for holding work to be welded. The "Electronic Tornado" welding head can be furnished with or without wire feeding attachment for use where additional filler metal is required. It is furnished for a continuous welding process in which pipe, tubing and similar work is fed under the arc.

The "Electronic Tornado" welding head is incorporated also in a self-propelled tractor type machine used for welding longitudinal seams in large diameter pipe and for flat plate work of large area.

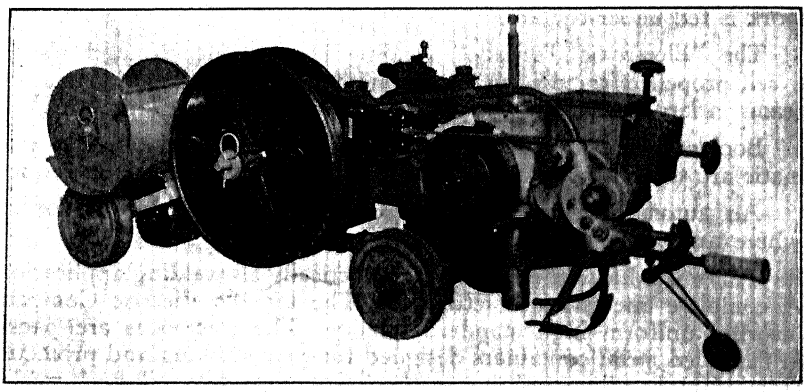
Booklets and bulletins containing complete information on automatic arc welding with Lincoln equipment are available upon request.

An automatic electrode feeder is also built by Lincoln for use where automatic metallic arc welding is required.

There is a Lincoln electrode for practically all welding applications. A complete line is manufactured by The Lincoln Electric Company, insuring uniform high standard quality. The electrodes are packed in flat sided metal containers designed for easy stacking and protection from rough handling and the weather. Complete data will be furnished gladly for any type Lincoln electrode requested.

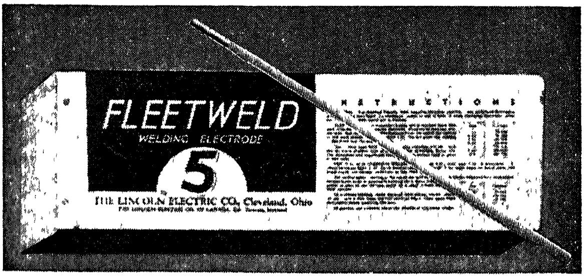


Lincoln "Electronic Tornado" automatic welding head with wire feeder.



Lincoln "Electronic Tornado" automatic tractor type welder.

Lincoln Electrodes



"Fleetweld 5" **Electrodes (Type A) for welding mild steel in all positions.**—Specially designed for shielded arc welding in all positions where high tensile strength and high ductility are desired. "Fleetweld 5" is a high-speed smooth-flowing electrode. It produces weld metal possessing a tensile strength of 65,000 to 77,000 pounds per square inch; elongation in two inches of 19 to 26 per cent; impact resistance of 30-70 foot pounds Izod; fatigue resistance, 28,000-32,000 pounds per square inch; density, approximately 7.84-7.86 grams per c.c.; resistance to corrosion greater than mild steel. Welds can be flanged or bent cold and forged.

"Fleetweld 7" **Electrodes (Type B) for single pass welding of mild steel, also for poor fit-up of work.**—A general purpose heavily coated electrode for welding with the shielded arc on mild steel. Designed for high speed and single pass welding. Particularly suitable for welds where fit-up is apt to be poor. Has a high burn-off rate and low splatter loss, providing exceptionally fast welding at low cost. The finished bead is smooth. Tests made on specimens of all-weld metal show the following characteristics: Tensile strength 71,000 to 82,000 pounds per square inch; yield point 57,000 to 65,000 pounds per square inch; elongation in two inches 15–21%; impact resistance 25-50 foot pounds Izod; fatigue resistance 25,000-30,000 pounds per square inch; density 7.82-7.86 grams per c.c.; resistance to corrosion comparable to mild steel.

"Fleetweld 8" **Electrodes (Type C) for fillet welding mild steel in flat position.**—A heavily coated electrode of the shielded arc type designed specifically for making fillet welds in mild steel plate, flat position. In one pass, with one plate vertical, the ¼ inch size will produce fillets up to ⅜ inch size. Sizes larger than ¼ inch should be used only for positioned work. "Fleetweld 8" produces smooth, dense welds with no undercutting at the vertical plate and no overlap at the horizontal plate. In the as-welded state, welds have tensile strengths of 65,000 to 74,000 lbs. per sq. in., elongation in two inches of 21-27%. Stress relieved, tensile strengths range between 62,000 and 71,000 lbs. per sq. in., and elongation in two inches of 28-33%.

"Fleetweld 9" **Electrodes (Type C) for deep-groove welding of mild steel in flat position.**—A heavily coated electrode designed for

the shielded arc welding of deep-groove joints in mild steel plate, flat position. In addition to having a high melting rate, "Fleetweld 9" has a very low spatter and slag loss. Weld metal produced by "Fleetweld 9" in mild steel has a tensile strength of 67,000 to 69,000 lbs. per sq. in.; elongation in two inches of 21-28%; impact resistance, 30 to 60 ft. lbs. Izod; fatigue resistance 28,000 to 32,000 lbs. per sq. in.; density approximately 7.84 to 7.86 grams per c.c.; resistance to corrosion greater than mild steel.

"Fleetweld 9-HT" **Electrodes (Type C) for flat welding of deep-groove joints in high tensile steels.**—A heavily coated electrode of the shielded arc type. Designed specifically for flat welding of deep-groove joints in the higher tensile steels now being used in the construction of pressure vessels. This electrode is outstanding for its high deposition rate, low spatter loss, easily removable slag, well shaped beads, and density of deposit. Stress relieved at 1200° F., welds have tensile strength of 74,000 to 76,000 lbs. per sq. in.; yield point, 58,000 to 61,000 lbs. per sq. in., elongation in 2 inches 28-29%; specific gravity 7.84 to 7.86 gms. per c.c.; impact strength, 30 to 50 lbs. (Izod); endurance limit, 40,000 to 45,000 lbs. per sq. in.

"Fleetweld 10" **Electrodes (Type C) for last pass, flat position in mild steel.**—A heavily coated electrode of the shielded arc type designed specifically for making the final pass in a multiple-pass, downhand weld on flat surfaces in mild steel. It provides full slag coverage and produces an exceptionally smooth bead. Tensile strength of weld metal is 68,000 to 70,000 pounds per square inch. Elongation in two inches is 22% to 26%.

"Stable-Arc" **Electrodes for general purpose welding.**—A washed rod, readily identified by its blue color. "Stable-Arc" (non-splashing) electrode conforms to A.W.S. Specification E4511 and is chemically analyzed frequently during its manufacture to insure an absolutely uniform rod. Its weldability is double checked by actual factory welding tests in downward, vertical and overhead positions. It largely eliminates the splatter and splashing of hot metal, steadies the arc, produces a smoother bead with a remarkably clean finish, and increases ductility of the weld. Being a fast flowing rod and non-splashing it welds faster with excellent penetration.

"Lightweld" **Electrodes for welding light gauge sheet metal.**—Specially designed for welding 16 to 22 gauge and making butt, lap or corner joints. It will give a dense weld free from pin holes with considerable ductility. The weld can be readily bent with no sign of fractures. Is a metal electrode and will give typical shielded arc weld metal. Very high speeds can be made with resulting low cost.

"Transweld" **and** ***"Readyweld"*** **Electrodes (Type B) for welding with small a.c. outfits.**—A heavily coated electrode providing extremely stable arc for smooth, strong, ductile welds with small a.c. welders. Also operates equally well with d.c. Tensile strength 82,000 to 84,000 lbs. per sq. inch. Elongation in two inches 17 to 20%.

"Shield-Arc 85" **Electrodes (Type A) for welding high tensile steels.**—A heavily coated electrode for welding by the shielded arc process. It is designed for use in high tensile steels, low carbon nickel steels, structural silicon steels, and in general all low alloy steels under .30 per cent carbon. On such steels "Shield-Arc 85" produces welds of 77,000 to 82,000 pounds per square inch tensile strength; yield point of 61,000 to 66,000 pounds per square inch; elongation in two inches 17-24%; impact resistance 30 to 70 foot pounds Izod; fatigue resistance 42,000 to 46,000 pounds per square inch; density 7.84 to 7.86 grams per c.c. "Shield-Arc 85" has steady arc characteristics and will provide a smooth uniform weld deposit.

"Shield-Arc 100" **Electrodes for welding high tensile steels.**—A shielded arc type electrode developed for welding steels having somewhat higher ultimate strengths than those ordinarily welded with "Shield-Arc 85" electrodes. Welds produced by "Shield-Arc 100," in the higher tensile steels, possess ultimate strength of 95,000 to 105,000 pounds per square inch as welded; elongation in two inches 14-20%; fatigue resistance 45,000 to 55,000 pounds per square inch.

"Stainweld A-5" **Electrodes for welding 18-8 stainless steels.**—Provides weld metal of the proper physical and chemical properties for welding 18-8 stainless steels. A coating is provided on the electrode which prevents oxidation of the weld metal and keeps the analysis of the deposited metal virtually the same as the parent metal and gives a bead of the "A" type (see Procedure Handbook, Page 148). Due to this, welds are of high tensile strength and ductility and possess similar resistant qualities to the parent metal.

"Stainweld A-7" **Electrodes for welding 18-8 stainless steels.**—Produces a weld of the characteristics of 18% chromium, 8% nickel steel. Its coating prevents oxidation of weld metal and produces a bead of the "B" type (see Procedure Handbook, Page 150).

"Stainweld B" **Electrodes for welding 25-12 stainless steels.**—Produces weld metal of the same characteristics as steel containing 25% chromium and 12% nickel. The electrode's high chrome content makes it advantageous for welding stainless-clad steels. Welds provided by this electrode have the high corrosion-resistance, high tensile strength and ductility possessed by the 25-12 alloy steels. Tensile strength: 95,000 to 105,000 lbs. per sq. in.

"Stainweld C" **Electrodes for welding 18-8 SMO stainless steels.**—A coated electrode designed for welding the stainless steels of the 18% chromium, 8% nickel and molybdenum content. These are designated by Iron & Steel Institute as Types 316-317. Molybdenum content of approximately 3½% gives these steels greater resistance to corrosion of certain chemicals than does the 18-8S type.

"Stainweld D" **Electrodes for welding 25-20 stainless steels.**—Produces weld metal of the characteristics of 25% chromium, 20% nickel steel (ISI Type 310). Beads are of the "A" type (see Procedure Handbook, Page 148). Coating prevents oxidation and assures strong, ductile welds with resistant qualities similar to the parent metal.

***"Chromeweld 4-6"* Electrodes for welding 4-6 chrome steels.**—Provides welds having the high creep strength and resistance to oxidation required in applications for the 5% chromium steels. These are used extensively in oil refinery equipment, in making superheater headers for steam generating units, etc. These steels and "Chromeweld 4-6" welds are highly resistant to crude oil corrosion. When fully annealed, the weld metal possesses these physical properties: Ultimate tensile strength 65,000-75,000 lbs. per sq. in.; ductility, elongation in two inches, 35-50%; hardness (Brinell) 130-140. When stress relieved, weld metal has tensile strength of 80,000-90,000 lbs. per sq. in.

***"Nickelchromeweld"* Electrodes for welding Inconel, Nichrome and similar alloys.**—Shielded arc type contains 70-80% nickel and 11-15% chromium. Produces dense, easily-polished welds of high corrosion-resistance.

***"Planeweld"* Electrodes for welding SAE 4130 and X 4130 steels** such as used in landing gears, tail wheel assemblies, etc. Produces smooth welds in all positions, which respond to heat treatment like parent metal.

***"Manganweld"* Electrodes for welding high-manganese steel.**—Coated electrode. Produces a weld deposit of austenitic manganese-nickel-molybdenum steel which is particularly suitable for reclaiming worn austenitic steel parts. Welds produced by this electrode are equal in wear resisting qualities to heat-treated cast manganese steel. The weld metal is air-toughening and remains in the austenitic state even with the reheating required in laying several beads directly over one another. Welds, as deposited, have a hardness of 5 to 10 Rockwell C. Cold working increases hardness to 45 to 50 Rockwell C. "Manganweld" electrode differs from ordinary manganese steel electrodes in that it melts uniformly in small particles with a minimum of arc disturbance and boiling in the arc crater.

***"Manganweld B"* Electrodes for high manganese steel.**—A *bare* electrode designed for building up worn manganese steel parts of 11%-14% manganese. Produces an air-toughening deposit of austenitic manganese-nickel-molybdenum steel which is equal in wear resistance to heat-treated cast manganese steel. Cold working increases hardness to 45 to 50 Rockwell C.

***"Hardweld 100"* Electrodes for wear resistance.**—A high carbon electrode containing about 1.00% carbon, designed for the building up of steel parts to produce a dense tough surface of moderate hardness—to resist shock and abrasion. The exact hardness of the deposit depends upon the rate of cooling and also somewhat upon the carbon content of the steel being built up. When deposited on straight carbon steel and allowed to cool naturally, hardness will be within the following range: Rockwell C—20 to 45; Scleroscope 31 to 61; Brinell 225 to 425. A weld of 33 Rockwell C hardness increases to 40 Rockwell C when peened. Quenching in cold water from 1450 degrees F. increases hardness to 50 Rockwell C.

***"Hardweld 50"* Electrodes for wear resistance.**—This is a medium carbon steel electrode (approximately .50% carbon) designed for build-

ing up steel parts and surfaces to resist deformation and wear and to produce a tough, dense deposit that is machinable at slow speed.

***"Wearweld"* Electrodes for shock and abrasion.**—A shielded arc type electrode for building up steel surfaces to resist shock and abrasion. Deposits are air hardening alloy steel with unusual hardness and toughness. This electrode can be used to build up all steels other than those of austenitic type, and for some service even on austenitic steels. Particularly valuable for facing parts, subjected to rolling or sliding abrasion, batter, and repeated impact. A single layer on mild steel has a hardness of 40 to 45 Rockwell C. Additional layers will have a hardness of 48 to 52 Rockwell C. On .70 carbon steel a single layer will have a hardness of 50 to 55 Rockwell C.

***"Abrasoweld"* Electrodes for severe abrasion.**—Meets the requirements for building up straight carbon steel, low-alloy or high manganese steel surfaces to resist abrasion in applications where pronounced battering and impact are not encountered. It deposits an abrasion resisting alloy of the self-hardening type, which hardens very rapidly under conditions of impact and abrasion. For example, moderate peening will increase hardness as deposited from 20-30 Rockwell C to approximately 50 Rockwell C. "Abrasoweld" maintains its toughness and develops its maximum hardness only at the surface where it is cold worked. Deposit is more resistant to corrosion than high manganese steel. It can be forged hot without materially altering its physical properties.

***"Faceweld"* Electrodes for abrasion resistance.**—Coated electrodes in types No. 1 (yellow tip) and No. 12 (red tip). No. 1 has good abrasion resistance (hardness of 45-52 Rockwell C) and excellent impact resistance. No. 12 has exceptional abrasion resistance (hardness of 52-57 Rockwell C) and moderate impact resistance.

***"Surfaceweld A"* for severe abrasion.**—A fine-grained alloyed powder to be applied with carbon arc to produce a smooth, dense, abrasion-resisting surface. It can be applied in a very thin layer if desired. Hence it is usually used on thin parts subject to wear due to abrasion.

***"Toolweld"* Electrodes for building up cutting edges on tools.**—A coated electrode for building up cutting edges on metal and woodworking tools. It produces weld metal equivalent to high speed tool steel. Although the weld metal, as deposited without heat treatment, has a hardness of between 55 and 65 Rockwell C, the degree of hardness will vary somewhat depending upon the admixture of base metal with the weld deposit. In general, hardness is increased by permitting deposit to cool slowly and by depositing additional beads. With two beads, which largely eliminate admixture of base metal, hardness will be above 60 Rockwell C. Deposit retains its hardness at relatively high temperature (approximately 1000 degrees Fahrenheit). Welds can be heat treated the same as high speed steel. Deposit is very dense and practically free from porosity if electrode is properly handled.

***"Ferroweld"* Electrodes for welding cast iron.**—A coated electrode with a steel base which will give a solid weld on cast iron of a greater tensile strength in all cases than the cast iron itself. It makes a good bond or union with cast iron and, due to the low current which can be used on it, the hardening effect usually present along the line of fusion is materially reduced, thus making a weld with this rod much more machinable than most rods now on the market for this purpose.

***"Softweld"* Electrodes for machinable welds on cast iron.**—A coated non-ferrous alloy electrode that produces a soft deposit on cast iron to repair blow-holes, defects and breaks and provide easy machinability.

***"Aluminweld"* Electrodes for welding aluminum.**—A 5% Silicon Aluminum alloy for welding sheet or cast aluminum. It is designed for either metallic or carbon arc welding. It is provided with a coating which prevents excessive oxidation and will dissolve any aluminum oxide which might be formed. The coating also assists in giving a very smooth operating arc which is so particularly essential in welding aluminum. The resulting weld is very dense without porosity and possesses high tensile strength. The weld can be polished satisfactorily with practically no discoloration.

***"Aerisweld"* Electrodes for welding bronze, brass and copper.**—A shielded arc electrode which produces weld deposits having the characteristics of true phosphor bronze with notably high tensile strength. Applications for "Aerisweld" include—bus bars, large contacts, impeller blades in pumps and turbines, ornamental bronze and bronze doors, etc. "Aerisweld" readily welds many types of bronzes which are difficult to braze; also galvanized sheets. In repair of worn parts, the electrode builds up and fills in bronze castings such as journal boxes and containers; bronze valve seats and bearing surfaces on steel or cast iron. No preheating of parts is necessary except on heavy bronze or copper.

***"Anode"* Electrodes** are the non-ferrous type. Used principally to produce machinable welds in cast iron. The welds have good tensile strength.

***"Kathode"* Electrodes**—fuse easily with deep penetration, producing welds in mild steel which are easily machined.

Carbon Electrodes—used for manual carbon arc welding and cutting are included in Lincoln's complete line of electrodes. Lincoln carbon electrodes are the high quality baked type.

Automatic welding with the Electronic Tornado welding head requires use of Lincoln "Weldmore" carbon electrodes. These carbon electrodes are impregnated and will not swell under welding heat. They are carefully ground to size. Each electrode is inspected for straightness and gauged for size. The life of "Weldmore" carbon electrodes is very much greater than ordinary carbons.

Lincoln Welding Supplies

Lincoln's complete line of accessories and supplies is used in the majority of welding shops the world over. This vast proving ground brings out design improvements which keep this line of supplies far in the lead in assuring maximum welding economy, quality and safety.

Electrode Holders—available in all types and sizes for every welding purpose: for currents up to 500 amperes intermittent and 350 amperes continuous; for high capacity welding on d.c. or any commercial a.c. circuit; for light work; for welding with a carbon arc which may require a light holder, or one water-cooled, or air-cooled.

Face and Head Shields—supplied in a variety of types and styles to meet any requirement. Lincoln protective shields are made of durable non-reflecting dead black fibre and are fitted with high-quality lenses which can be depended upon to absorb all objectionable rays emanating from the arc. Lenses of Lincoln shields are protected by a chemically treated non-spatter cover glass which protects and yet allows greatest visibility.

Protective Clothing—including welder's gloves, mitts, sleevelets, aprons, leggings, spats, made of all-chrome-leather or other fire-resisting materials.

Cable and Cable Accessories—including Lincoln "Stable-Arc" cable, providing maximum flexibility and long service life under usual conditions; also thoroughly dependable cable for ground or motor service. Cable accessories include lugs, plugs and receptacles and connectors, either for making permanent connections or for quick detachability.

Linconditioner—This Lincoln shop air cleaner filters the smoke and removes the heat of welding and thereby contributes materially to the comfort of the man-at-the-arc, resulting in less fatigue, better work and lower costs.

Wire Welder's Brushes—designed especially for cleaning the work preparatory to welding and for cleaning welds between beads. Lincoln brushes have bristles of special tempered wire providing exactly the right amount of stiffness.

Welding Booths—having sturdy pipe framework with side walls of fire-resisting duck. Booths are light weight and can be assembled in only a few minutes.

Automatic Welding Supplies—for use with the Lincoln "Electronic Tornado" automatic arc welder—include autogenizers, "Weldmore" carbon electrodes and filler metal.

All the above equipment and Lincoln's full line of electrodes are completely catalogued in the Lincoln Supply Bulletin, copies of which will be furnished gratis upon request.

Lincoln Engineering Service

On the staff of its welding engineering department, Lincoln retains a welding and engineering authority of national prominence as Consulting Engineer. The services of Lincoln's Consulting Engineer and the entire welding engineering department are available to manufacturers

at actual cost for consultation work and aid on problems of design and redesign of products and the application of welding to their manufacture.

Hundreds of companies rely upon this personal type of engineering service as a source of authoritative and unbiased aid in the solution of their manufacturing problems. Lincoln's engineering service is available to all regardless of the type of welding equipment involved.

Lincoln Engineering Data

Because its equipment is extensively used in practically every industry, Lincoln has collected what is said to be the most complete file of engineering data on almost all applications of welding, both large and small. The contents of this volume serve only as an indication of the completeness and range of this data. Inquiries from responsible sources for engineering data will be gladly fulfilled gratis.

The Lincoln Electric Company publishes periodically bulletins and leaflets on almost all phases of arc welding and its applications. These bulletins on any subject are available without charge upon request.

Lincoln Welding School

A school for the training of men in the art of arc welding is maintained at The Lincoln Electric Company, Cleveland, Ohio. Here a complete four weeks' training course in practical arc welding is given, under the supervision and direction of competent and practical instructors. This highly practical course includes teaching and practice in the fundamentals of welding. Subjects covered include: With shielded arc electrode—the shielded arc and its uses; study of the arc welding generator; running horizontal bead; running bead not less than 12″ long; weaving the electrode; effect of arc length, current and speed on bead; effect of polarity on bead; various electrodes, sizes and uses; padding, building up plates; building up shaft; vertical, horizontal and overhead welding of lap, butt, tee welds, etc.; expansion and contraction; penetration; cutting, etc. Welding with bare electrode is also covered to provide the student complete training in all phases of welding.

During the nearly twenty years through which the Welding School has been conducted without interruption, it has trained thousands of men in the art of electric welding. The wide interest shown in the School is indicated by the fact that enrollment runs several months in advance of the actual sessions. The service is rendered free of charge to purchasers and users of Lincoln equipment. For others, a small nominal fee is charged. The lessons, a series of 42 containing over 100 mimeographed pages and well illustrated by sketches, are available at a very moderate cost. Full particulars regarding the Welding School may be obtained by writing the company.

An Advanced Welding Course for engineers and experienced operators is given at intervals by the John Huntington Polytechnic Institute, Cleveland, Ohio with the assistance of The Lincoln Electric Company. This course consists of one week's intensive study of welding design which includes the theory and practice of arc welding.

The Lincoln welding school gives 120 hours' practical training.

The course covers: the shielded arc, its value and use in design; inspecting welds; checking fusion and penetration; calculating stress distribution in welded joints; use of rubber weld models and polarized light in the study of stress distribution; a simple metallurgical study of the welding of ferrous and non-ferrous metals; determination of the most economical section in changing from cast to arc welded construction; organizing the welding department; estimating welding costs. A fee of ten dollars, charged for the materials used in practice work, is the only fee for this course. Complete information may be obtained from John Huntington Polytechnic Institute, Cleveland, Ohio, or from the Welding Engineering Dept., of the company.

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